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Test Standards for Contingency Base Waste-to-Energy Technologies

by Jesse A Margolin, Philip A Marrone, Margaret A Randel, William R Allmon, Rodrick B McLean, and Paul M Bozoian

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14. ABSTRACT

In collaboration with the Joint Deployable Waste to Energy (JDW2E) Community of Interest (COI), the US Army Research Laboratory (ARL), and the US Natick Soldier Research, Development and Engineering Center (NSRDEC), Leidos developed test standards for waste-to-energy (WTE) systems applicable to Department of Defense (DOD) contingency bases. The benefits of using test standards are to 1) provide common test criteria to allow better comparison between systems, 2) ensure that key emissions characteristics of WTE systems are measured to better understand applicability to various regulatory or operational requirements, 3) ensure that key performance attributes are measured to better align WTE systems with appropriate applications, 4) establish baseline data for WTE systems that could be beneficial for future end users, and 5) identify common data gaps or areas for future research and development. The test standards prepared for this study provide the recommended materials and the proportion of those materials that can be used to simulate contingency base waste and identify universal criteria that should be measured and evaluated when testing WTE systems for contingency bases to include characterization and quantification of the feed, emissions (gas, liquid, and solids), consumables, and operations and performance metrics.

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1. Introduction

1.1 Background

Traditional Department of Defense (DOD) methods of solid, non-hazardous waste disposal at overseas US Armed Forces Contingency Bases (e.g., open air burn pits, burn boxes) pose significant health, safety, and environmental concerns. In addition, because fuel delivery to these bases is expensive and a safety risk, there is motivation to reduce energy requirements. Waste-to-energy (WTE) technologies have the advantage of not only addressing waste disposal issues, but also recovering a portion of the energy contained in the waste materials and conserving fuel. As a result, there is significant interest by the DOD in using WTE technologies at contingency bases.

In collaboration with the Joint Deployable Waste to Energy (JDW2E) Community of Interest (COI), the US Army Research Laboratory (ARL), and the US Army Corps of Engineers – Engineer Research and Development Center – Construction Engineering Research Laboratory (USACE-ERDC-CERL), Leidos evaluated a number of applicable WTE systems. This study, referred to as Phase I, performed the following tasks:

- Established criteria for WTE systems applicable to contingency bases;
- Identified 64 companies with systems potentially applicable to the criteria established;
- Performed independent engineering evaluations of four systems; and
- Prepared a company database and evaluation report that was issued in May 2014.[1]

Building on these Phase I results, ARL and Leidos combined efforts with the US Army Natick Soldier Research, Development and Engineering Center (NSRDEC) and performed a study referred to as Phase II that included 4 tasks:

- Task 1: Review existing waste characterization studies performed at contingency bases and recommend a representative "standard" test profile of the waste materials that can be used when evaluating potential WTE systems;
- Task 2: Identify key operational aspects at contingency bases as they pertain to storing, handling, and disposing of wastes, and evaluate any impacts they may have on integrating potential WTE systems;

- Task 3: Develop test standards that can be used when performing demonstration testing of WTE systems to help quantify demonstration results and support system comparisons; and
- Task 4: Plan, oversee, and evaluate a number of demonstration testing programs to advance WTE technologies and/or fill key data gaps.

This report documents the efforts and results of Task 3.

1.2 Purpose

In order to perform demonstration testing of potential WTE systems in support of Task 4, test standards need to be identified that provide universal criteria for measurement and evaluation. The benefits of performing test programs using test standards include the following:

1. Provide common test criteria to allow better comparison between systems;
2. Ensure that key emissions characteristics of WTE systems are measured to better understand applicability to various regulatory or operational requirements;
3. Ensure that key performance attributes are measured to better align WTE systems with appropriate applications;
4. Establish baseline data for WTE systems that could be beneficial for future end users; and
5. Identify common data gaps or areas for future research and development to allow advancement in WTE technology to meet current and future needs at contingency bases.

1.3 Scope and Objectives

The overall scope of this task is to prepare universal test standards applicable to extra small (50–299 personnel [PAX]) and small (300–1999 PAX) contingency base camp sizes. Specifically, the test standards are intended for the force provider expeditionary (FPE) 150- and 600-PAX camps that are anticipated to generate 0.5 to 2 tons per day (tpd) of waste. These base camp sizes were selected based on the requirements in the US Army Force Provider Expeditionary (FPE) Capability Production Document (CPD).[2] The FPE CPD establishes Threshold and Objective Requirements for solid waste management capability with individual modules (150 PAX) and collocated modules (600 PAX) as shown in Table 1.

Table 1 Threshold and objective requirements provided in the CPD for FPE

Camp Size	Paragraph[2]	Threshold Requirement	Objective Requirement
150 PAX (750–1200 lb/day)	6.2.63(U) APA 20b	The FPE shall incorporate an integrated waste management (reduction, reuse, recycling, treatment, or disposal process) add-on capability that can safely process 1000 lbs or more of mixed solid organic waste in a single day onsite.	The energy associated with the management process shall be converted to usable energy including fuel, heat or electric power.
600 PAX (3000–4000 lb/day)	6.2.62(U) APA 20a	The FPE shall incorporate an integrated waste management (reduction, reuse, recycling, treatment, or disposal process) add-on capability that can safely process 2 tons of mixed solid organic waste in a single day onsite.	The energy associated with the management process shall be converted to usable energy including fuel, heat or electric power.

The specific objectives of this task are as follows:

1) Select materials that can be used to simulate contingency base waste recipes identified in Task 1 that can be used for standardized testing to allow system performance to be compared to other systems that have been operated under similar conditions;

2) Identify universal criteria that should be measured and evaluated when testing WTE systems for 150- and 600-PAX contingency bases to include characterization and quantification of the feed, emissions (gas, liquid, and solids), consumables, and operations and performance metrics; and

3) Prepare a test standards document that consolidates the information obtained and discusses any impact the test standards may have on WTE technologies.

It should be noted that although the scope and objectives of this task pertain to the US Army extra small and small contingency base sizes, the results could be applicable to other military services and other base camp sizes. Using a standard recipe to test WTE systems across military services would allow the systems to be compared to each other on a uniform basis.

1.4 Approach

To accomplish this task, input was solicited from Government personnel, JDW2E COI participants, and other specialists to encourage collaborative development of the test standards and simulated waste feed recipes. The specific approach includes the following:

1) Develop a universal test concept that can be applied to waste destruction and/or WTE technologies (Section 2);

2) Identify the predominant types of wastes that comprise each waste category based on historical waste characterization studies and Government input, and prepare a list of surrogates that can be combined together to be used as a representative simulant recipe for contingency base wastes (Section 3);

3) Establish a data collection standard (sampling/analytical data, process data, and operational data) using subject matter expert input and industry experience based on information obtained from historical regulatory/operational requirements, baseline incineration and burn pit studies, and other contingency base waste test programs (Section 4); and

4) Prepare guidance for the preparation of standard test documentation to ensure the information obtained from each test program is complete and can be compared to other test programs that used the test standards (Section 5).

2. Test Concept

A challenge in evaluating the performance of WTE systems is the inherent variability of the feed materials such as those derived from typical sources of Army base wastes or municipal solid waste (MSW). Based on the results of the Phase I study, it was found that most WTE system data were collected by testing with these feed sources. There are significant economic advantages in using Army base wastes or MSW to collect operational and maintenance data. However, the disadvantages are that 1) the performance (e.g., energy recovery, emissions, fuel usage) is dependent on the contents of the feed which is largely unknown; 2) the variability in the waste could lead to false conclusions regarding typical results; and 3) comparing the performance between WTE systems is difficult if the waste feed materials are different from one test to another.

In order to address this challenge, it is recommended that 2 types of tests be performed to adequately evaluate a system: 1) capability testing with a standard recipe(s) and 2) operational performance testing with actual base wastes. Capability testing is typically performed with a number of short-duration tests with known, simulated waste materials so that the capability of the system can be assessed under known conditions and compared to other systems that have been operated under similar conditions. The operational performance testing is performed for longer durations using actual waste materials to focus on the operational performance of the system under "real world" conditions that the simulated wastes may not be able to fully represent. Each test type has its own objectives and benefits, as shown in Fig. 1.

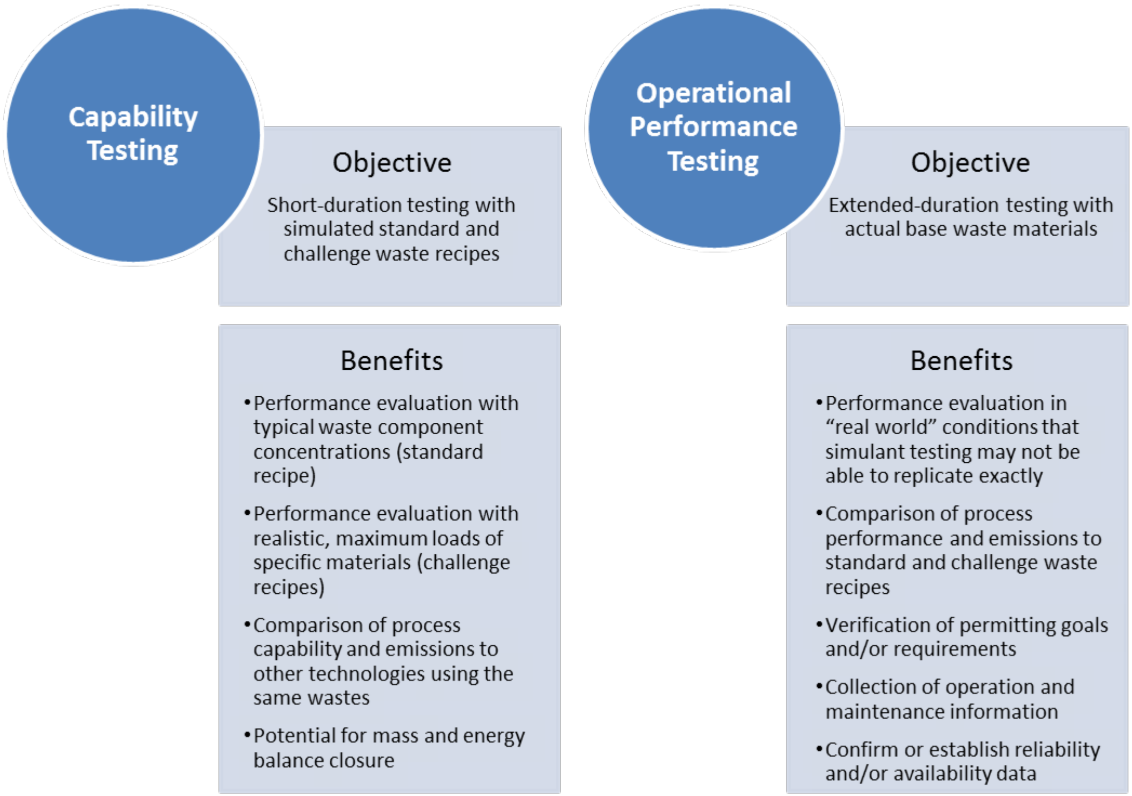

Fig. 1 Standard test types for evaluating technologies

The standard and the 4 challenge recipes that should be used as the feed material for the capability testing are described in Section 3. For the operational performance testing, it is recommended that the base waste materials that are used for testing be characterized to estimate the composition. This characterization can be accomplished by grouping the waste component into the standard categories as described in *Waste Characterization Analysis and Standard Test Recipe Development for Contingency Bases*.[3] Characterizing the wastes will allow the composition of the base waste materials to be compared to the standard recipe (and the results from the capability tests) and help interpret performance and emissions data results.

For capability testing, a minimum of 3 test runs at normal capacity using the standard recipe should be performed followed by a minimum of 1 test run using each of the 4 challenge recipes. These 7 test runs are selected as a minimum to keep test execution and sampling/analysis costs low. However, additional test runs are preferred to allow a more comprehensive statistical evaluation of the results. In addition, workup runs should be performed to verify that sampling and analysis equipment and procedures are adequate.

The recommended duration of each test is dependent on the system and its configuration. However, a guideline for continuous systems is that each test run should be performed for a duration that will allow representative samples to be collected during steady state operations. For batch systems, multiple samples may need to be collected over the run to characterize performance from different operational periods (e.g., start-up, peak burn, cool-down).

3. Standard and Challenge Recipe Preparation

Historical waste characterization studies performed at military bases were evaluated in Task 1 of this study. Based on the evaluation, recommendations were prepared for a representative base case "standard recipe" that should be used when testing and evaluating WTE systems. In addition to the standard recipe, "challenge recipes" were developed that contain high concentrations of specific components that can be used when testing and evaluating WTE systems to simulate credible worst case scenarios. The resulting recommendations of this evaluation are shown in Tables 2 and 3. Table 2 provides the recommended distribution of various waste categories for both the standard and challenge recipes. Table 3 shows the breakout for the specific types of plastics in the recipe.

Table 2 Recommended standard and challenge recipes by weight percent

Waste Category	Standard Recipe	Challenge Recipe Cardboard/Paper	Challenge Recipe Food	Challenge Recipe Plastic	Challenge Recipe Wood
Cardboard	15%	**19%**	11%	10%	10%
Mixed paper	10%	**38%**	7%	6%	6%
Food waste	32%	18%	**51%**	21%	21%
Plastic (total)[1]	15%	8%	11%	**44%**	10%
Wood	14%	8%	10%	9%	**43%**
Metals[2]	6%	3%	4%	4%	4%
Glass	1%	1%	1%	1%	1%
Rubber and neoprene	1%	1%	1%	1%	1%
Textile	3%	2%	2%	2%	2%
Miscellaneous Waste/Other	3%	2%	2%	2%	2%
Total	100%	100%	100%	100%	100%

Note: All values shown are weight percentages. Values were adjusted for round-off errors and percentages are provided as whole numbers. The numbers in bold represent the waste category that is being challenged.

[1] Further breakdown of plastic types is provided in Table 3.

[2] Recommended breakdown of metal types is 60% ferrous (iron), 36% aluminum, and 4% other metals.

Table 3 **Recommended breakout of plastic recipes by weight percent**

Plastic Type	Standard Recipe	Challenge Recipe Plastic (Total)	Challenge Recipe #1 PET (Opt)	Challenge Recipe #3 PVC (Opt)	Challenge Recipe #6 PS (Op)
Plastic (total)	15%	44%	44%	44%	44%
#1 PET	6.0%	17.7%	**27.8%**	12.9%	11.1%
#2 HDPE	2.7%	7.8%	4.8%	5.7%	4.9%
#3 PVC	0.9%	2.6%	1.6%	**13.7%**	1.6%
#4 LDPE	2.7%	7.8%	4.8%	5.7%	4.9%
#5 PP	0.3%	0.8%	0.5%	0.6%	0.5%
#6 PS	1.8%	5.4%	3.3%	4.0%	**19.6%**
#7 Other	0.6%	1.6%	1.0%	1.2%	1.0%

Notes: All values shown are weight percentages. Values were adjusted for round-off errors and percentages are provided as whole numbers. The numbers in bold represent the plastic type that is being challenged. PET = polyethylene terephthalate, HDPE = high density polyethylene, PVC = polyvinyl chloride, LDPE = low density polyethylene, PP = polypropylene, PS = polystyrene, Other = Other plastics that may include polycarbonate, acrylic, nylon, bioplastics, composites, etc.

Depending on the type of system that is being tested, there may be value in challenging not only the overall quantity of plastics, but different types of plastics. For example, 3 plastic types may pose challenges for a WTE system: 1) PET because of its relatively high amount due to surges in water bottle usage, 2) PVC because of the presence of chlorine, and 3) PS because of the aromatic rings in its molecular structure. For each optional challenge recipe, both the maximum overall plastic value and the maximum value of the plastic type being challenged (based on the historical waste characterization studies evaluated for his task) were used to determine the percentages shown. Details regarding the evaluation and the results shown in the tables are provided in *Waste Characterization Analysis and Standard Test Recipe Development for Contingency Bases*.[3]

The next step in preparing the standard recipe is to identify the sources and quantities of specific components that can be used to simulate each waste category. It is recognized that each system may have specific requirements or limitations, and each test program may have different opportunities to obtain representative waste feed materials. However, it is important that the standard recipe is consistent from test to test. The guidance provided below to select simulated materials for each waste category was developed with this in mind and the following objectives:

- Match the simulated materials as close as practical to the *majority* of the actual type and configuration of materials anticipated in the contingency base waste stream (the intent is not to simulate every possible waste material);
- Minimize the number of different simulated materials that will comprise each waste category;

- Minimize the complexity, difficulty, and cost in obtaining the simulated materials;
- Select simulated materials with a long shelf life, ease of distribution throughout the waste stream, and safe handling characteristics; and
- Select simulated materials that will allow for reproducibility of the recipe.

A forum was held on 17 October 2014 at NSRDEC with personnel familiar with contingency base waste handling operations. Based on this forum, and subsequent communications with additional subject matter experts, preliminary simulated waste feed recipes were developed for standardized testing. This information was prepared as a summary table that was distributed for Government input and ultimately consensus agreement. Table 4 provides the outcome of this forum and the resulting subject matter expert input with the recommended simulated waste feed materials for standardized testing. This table includes a summary of the types of materials observed at contingency bases for each standard waste category, the materials that are recommended to simulate the majority of the waste for each category, the justification for selecting those materials, examples of how to obtain those materials, and potential estimated costs based on those examples. In the examples provided, the cost basis is for a 1-ton batch of waste. A more detailed breakout of the simulated waste feed examples and their estimated cost for the standard recipe is provided in Appendix B.

Table 4 Recommended simulated waste feed materials for standardized testing

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
Cardboard	– Meal, Read-to-Eat (MRE) shipping boxes (non-corrugated and corrugated fiberboard) – Other shipping boxes (corrugated fiberboard)	– Small corrugated pads (small, flat sheets) OR – Recycled corrugated fiberboard	Most cardboard waste is comprised of MRE shipping boxes (12 MREs per box) and larger corrugated shipping boxes. Small corrugated pads are readily available, can be evenly distributed throughout the waste, and avoid the inherent variability in recycled corrugated fiberboard materials. Alternatively, recycled corrugated fiberboard may provide the lowest cost option.	Example 1 (300 lb): Small corrugated pads (11 inches x17 inches) are available for purchase with 50 pads/bundle (8lbs/bundle). 38 bundles are needed. Estimated cost of $608. Example 2 (300 lb): Recycled corrugated fiberboard from a recycling center or source generator (e.g., supermarkets). Cost will vary.
Mixed paper	– Food trays – Magazines – Books – Napkins – Paper towels – Office paper – Wrappers (shiny paper) – Bowls – Plates – Cups – Milk and juice cartons – MRE paper components – Paper-based containers	– Food trays (90%) – Office paper (10%) OR – Recycled mixed paper	A major contributor of the paper waste comes from food trays. Food trays in the simulated waste will represent the more bulky paper products and the office paper will represent the thinner paper products. Alternatively, recycled mixed paper may provide the lowest cost option.	Use of Army-specified food trays are preferred (NSN 7350-01-411-5266). Any non-coated office paper is acceptable. Example 1 (200 lb): Chinet® Beige 5-Compartment Molded Fiber Cafeteria Tray (8.5 inches x 10.5 inches) meets the Army specification. 5 cases of 500 trays are needed for 180 lb (90%). One box of office paper (20 lb) is needed. Total estimated cost is $476. Example 2 (200 lb): Recycled mixed paper from a recycling center or source generator (e.g., office location). Cost will vary.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
Food waste	– Unitized Group Ration - A Option (UGR-A) wastes – MRE wastes – Food scraps (bones, banana peels, apple cores) – Kitchen prep waste (vegetable choppings, fruit skins) – Milk – Fruit (apples, bananas, oranges)	Dry, packaged food-type mixture that contains the following as closely as practical: – 13-14% protein – 32-36% fat – 51-54% carbohydrates Addition of water just prior to processing to bring the total moisture content to 75%	UGR-A composition: – 14% protein – 32% fat – 54% carbohydrates MRE composition: – 13% protein – 36% fat – 51% carbohydrates Typical food waste contains 70-75% moisture content.	Packaged dry food or food-type materials are more practical for testing than unpackaged wet food materials due to storage concerns. Example 1 (640 lb): Gravy Train Beef Flavor (Dry) dog food contains 19% protein, 9% fat, 64% carbohydrates, and 8% "other" on a dry basis. Dog food can be purchased in bulk and vegetable oil can be added (100% fat) to bring ratios close to MRE/UGR proportions. Water can then be added prior to processing to bring moisture content to 75%. Approximately 133 lb of dog food, 40 lb of vegetable oil, and 467 lb (56 gal) of water are needed (estimated total cost of $162).
Plastic (see below for specific types of plastics)				
#1 PET	– Water bottles – Other beverage bottles	– PET bottles (new) without caps OR – Recycled PET bottles	Most PET plastic waste at bases is comprised of water bottles. Small PET bottles are easily purchased and can be evenly distributed throughout the waste. Alternatively, recycled PET bottles may provide the lowest cost option.	Example 1 (120 lb): 12 oz. PET clear plastic juice bottles can be purchased by the case (15 lb per 160 bottles). 8 cases are needed with an estimated cost of $720. Example 2 (120 lb): Recycled PET bottles from a recycling center. Cost will vary.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
#2 HDPE	– Consumer product containers – Bags (kitchen/ contractor type)	– HDPE containers (new) without lids OR – Recycled HDPE containers	Consumer product containers are the most common form of #2 plastic (e.g., milk jugs, shampoo containers). Small HDPE containers are easily purchased and can be evenly distributed throughout the waste. Alternatively, recycled HDPE containers may provide the lowest cost option.	Example 1 (54 lb): 12 oz. HDPE plastic juice bottles can be purchased by the case (30 lb per 500 bottles). 2 cases are needed with an estimated cost of $250. Example 2 (54 lb): Recycled HDPE containers from a recycling center. Cost will vary.
#3 PVC	– Shrink wrap – Medical tubing – Wire insulation – Bags – Piping – Hose – Box strapping	– PVC pipe segments	PVC pipe is low cost and can be obtained from any home improvement store. Pipe can be cut into small segments to ensure equal distribution throughout the waste.	Example 1 (18 lb): 1-1/2 inches x 10 ft PVC schedule 40 DWV plain end pipe (10.5 lb) can be purchased at any home improvement store. Need 2 pipes with an estimated cost of $11.
#4 LDPE	– Stretch wrap – Trash bags	– LDPE trash bags	LDPE is commonly used in plastic bags. The trash bags provided with the UGRs are LDPE.	Bags can be made of #2, 3, 4, or 5 plastic, but most trash bags are made of #4 plastic. Trash bags will need to be distributed evenly throughout the waste. Example 1 (54 lb): LDPE 30 gallon waste can liners can be purchased in bulk. An estimated total cost is $145.
#5 PP	– Single serve cereal bowls – Consumer product containers – Bags	– Disposable polypropylene cereal bowls	Cereal bowls are most representative of the polypropylene component of base waste.	Example 1 (6 lb): A case of polypropylene bowls (24 oz. size) can be purchased by the case (17 lb in a case of 300). Estimated cost of $31.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
#6 PS	– Styrofoam containers – Dining utensils – Packing peanuts	– Styrofoam containers (70%) – Dining utensils (30%)	Percentage split assumes three utensils are used per Styrofoam container. Average weight of utensils and containers used for calculation. Approximate weights are: Utensil 0.104 oz each; Styrofoam container 0.752 oz each.	Example 1 (36 lb): Polystyrene utensils (11 lb) and containers (25 lb) can be purchased by the case to provide the total 36 lb required. Total estimated cost is $130.
#7 **Other**	– Electronics – Compact discs – Headphones	– Compact discs (CDs)	Plastic #7 category is often polycarbonate or ABS. Compact discs are a common source of polycarbonate and can be easily obtained and distributed evenly throughout the waste feed.	Example 1 (12 lb): Blank CDs can be purchased in bulk to provide 12 lb of polycarbonate (approximately 3 packages of 100 CDs). The estimated cost is $51.
Wood	– Pallets – Crates – Scrap lumber (e.g., 2x4s and plywood)	– Kiln dried spruce, pine, or fir (SPF) 2x4s cut into small pieces to allow even distribution in waste	Most wood waste is derived from pallets, either in whole or broken parts. Pallets can be made from any type of hardwood (e.g., oak) or softwood (e.g., pine) as long as it can meet the military specification. SPF was selected to minimize costs and ensure the same type of wood is used for each test program.	Although the densities are significantly different between hardwood and softwood, the heating values in BTU/lb are similar. For example, white oak with density of 47.2 lb/ft^3 provides 6409 BTU/lb. White pine with density of 26.3 lb/ft^3 provides 6384 BTU/lb. There is a difference of only 0.4%. Example 1 (280 lb): 2x4s can be purchased from any home improvement store. Each 2x4 (8 ft. length) weighs approximately 11 lbs. 26 2x4x8s are required. The estimated cost is $78.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
Metals (see below for specific types of metals)				
Aluminum	– Beverage cans – Aluminum foil – Foil containers	– Recycled aluminum beverage cans OR – Aluminum flashing rolls cut into small pieces to allow for even distribution in waste	Beverage cans are a common source of aluminum. Recycled aluminum cans may provide the lowest cost option. If recycled cans are not available, rolls of aluminum flashing (cut into small pieces) can be used.	Example 1 (43.2 lb): Aluminum cans from recycling center. Cost will vary. Example 2 (43.2 lb): Rolls of aluminum flashing (0.0078 inch thick) can be purchased at any home improvement store (approximately 3 lb per roll). 15 rolls are needed with an estimated cost of $308.
Iron	– Food cans – Nails and cleats – Ammunition boxes – Banding material for pallets – Scrap metal (from furniture, vehicles, or buildings)	– New steel or tin coated steel cans (75%) – New non-coated, ferrous (steel) nails (25%) OR – Recycled steel cans	Food cans and nails are easily obtained and are intended to represent the total weight of iron waste. Adding individual cans and nails allows the metal to be evenly distributed throughout the waste. Alternatively, recycled steel cans may provide the lowest cost option.	Large pieces of metal from the motor pool are handled separately and not considered to be part of normal waste. Example 1 (72 lb): #10 cans made of steel or tin coated steel can be purchased in bulk (approximately 102 cans are needed for 54 lb). Nails can be purchased in bulk (one 30-lb box for the 18 lb needed). The estimated cost for both is $475. Example 2 (72 lb): Recycled steel cans from a recycling center. Cost will vary.
Other Non-Ferrous metals	– Brass components reported to have originated from ammunition linkages	– Small brass fittings or other small brass parts	Small brass fittings are easy to obtain and can be distributed evenly throughout the simulated waste.	NSRDEC reported that the ammunition linkages are stainless steel, not brass as observed. Brass components were likely derived from other sources. Example 1 (4.8 lb): Brass tubing compression unions can be purchased in packs of 10 (2 lb each) to make up the total brass content required. The estimated cost is $54.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
Glass	– Hot sauce bottles – Broken light bulbs – Broken headlights – Broken windshields – Beverage bottles (brought in from local area) – Hand mirror	– Small, empty glass bottles OR – Recycled glass containers	Empty glass bottles can be easily obtained and are less dangerous to handle than other sources of glass that may have sharp edges. Alternatively, recycled glass containers may provide the lowest cost option.	The glass hot sauces bottles in the MREs have recently been replaced with plastic packages according to NSRDEC. Example 1 (20 lb): Clear glass 12 oz bottles can be purchased in cases of 12 (8 lb each). Estimated cost for 3 cases is $84. Example 2 (20 lb): Glass from a recycling center. Cost will vary.
Rubber and neoprene	– Tires/tire scraps – Rubber gloves – Hoses – Straps	– Rubber mulch derived from recycled tire waste	Tires or parts of shredded tires are the main source of rubber in base waste, even though tires are not normally handled through solid waste collection practices. Rubber mulch is easily obtained, will allow even distribution in waste, and has most of the metals already removed.	Most used tires are backhauled or used for other purposes, but some may be disposed of as trash. Example 1 (20 lb): Classic Black Rubberific Mulch can be purchased in 16-lb bags (2 bags are needed). The manufacturer states that the rubber is from 100% recycled truck tires. Estimated cost is $60.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
Textiles	– Soiled cotton clothing (e.g., underclothes, T-shirts, socks, towels) – Cargo net pieces – Webbing or strapping – Rope and cord pieces – Tent fabric – Fence screening – Vehicle tarps – Shoes – Boots – Pillows – Blankets – Ammunition bandoleer – Army Combat Uniforms	– Cotton blend cloth material (e.g., recycled t-shirts or rags) OR – Used clothing or textile recycling	Clothing is the most common textile seen in base waste, followed by pieces of rope, net, and strapping. Fence screening material is seen in large quantities but only occasionally. Other items listed (including leather) are seen much less frequently. Recycled t-shirt materials sold as rags can be obtained easily and distributed evenly throughout the waste. Alternatively, used clothing from a donation center or a used clothing store may provide the lowest cost option.	Example 1 (60 lb): Cotton blend t-shirt materials (recycled materials sold as rags) can be purchased in bulk with an estimated cost of $101 to obtain the needed weight. Example 2 (60 lb): Used clothing can be obtained from a donation center, used clothing store, or other means. Cost will vary.

Table 4 Recommended simulated waste feed materials for standardized testing (continued)

Standard Waste Category	Observed Materials in Base Waste (Typical)	Recommended Simulated Waste	Justification	Notes and Example Simulated Wastes (Basis of 1-ton batch using standard recipe)
Miscellaneous waste/Other	– Disposable batteries – Electronic waste – Personal hygiene products – Light sticks – Paint – Pesticides – Aerosol cans – Compressed air cans – Broken furniture – Plastic bottles with urine or tobacco spit – Hazardous/medical waste (not typical or allowed in standard waste disposal)	– Full PET water bottles (70%) – Light sticks (10%) – Household compressed air cans (10%) – Household disposable alkaline batteries (10%)	Full water bottles will simulate the containers filled with liquids (non-food) that are not normally found in the non-hazardous solid waste. Light sticks, empty aerosol cans, and disposable alkaline batteries are common non-hazardous waste components that do not fall under the standard categories. These items can be easily obtained and evenly distributed in the waste.	Example 1 (60 lb): PET water bottles (full) can be purchased by the case (42 lb required). Cyalume ChemLight Military Grade light sticks can be purchased in bulk (packs of 500) to meet the required 6 lbs. Household compressed air containers (to simulate aerosol cans) can be purchased in bulk to meet the 6-lb requirement. AA alkaline batteries can be purchased in bulk to meet the 6-lb requirement. Estimated total cost is $263.

Some of the simulated waste categories offer an option to use materials that can be obtained in bulk from recycling centers instead of purchasing new materials. These categories include cardboard, mixed paper, plastics (#1 PET and #2 HDPE), metals (aluminum and iron), glass, and textiles. The advantage of using recycled materials is the potential cost savings. However, the disadvantage is that there could be variability in the recycled waste. For example, using recycled corrugated fiberboard (cardboard) instead of new, purchased materials from a single distributer could result in processing different adhesives and pulp blending resins, and will likely include other contaminants such as packaging tape and box straps. Another disadvantage of using recycled materials is that the composition and quality may vary significantly between different suppliers or locations. In order to keep the simulated waste recipes as consistent as possible, using new materials that can be purchased and shipped to the test location is recommended.

It should also be noted that the simulated materials will need to be distributed evenly prior to processing to best simulate how the base waste would be loaded into the equipment. Some of the materials may need to be reduced in size and mixed in with other wastes to accomplish this. The approach used will be dependent on the specific system being tested. For example, a batch system that feeds small bags periodically will require a different approach than a large batch system that requires a single load for each test. The approach selected for each test program needs to be detailed in the test plan.

Based on the example materials recommended for the simulated waste feed, calculations were performed to estimate the moisture content and heat content of the standard recipe and the four challenge recipes. Details for the calculations performed and the assumptions used are provided in Appendix C. A summary of the results are shown in Table 5.

Table 5 Estimated heat and moisture content for the simulated waste

Estimate	Standard Recipe	Cardboard/Paper Challenge	Food Challenge	Plastic Challenge	Wood Challenge
Moisture Content (%)	29.7%	19.5%	42.1%	19.5%	22.9%
Heat Content (BTU/lb) (Wet Basis)	5314	4841	4315	8038	6066
Heat Content (MMBTU/ton) (Wet Basis)	10.6	9.7	8.6	16.1	12.1

Note: Refer to Appendix C for calculations and assumptions.

4. Data Collection Standards

The data collection standards are divided into 3 categories; process data, sampling/analytical data, and operational data as described in the following section. Process data include the process conditions as they pertain to the system during waste processing. Sampling/analytical data include all physical samples collected for analysis to include the gas, solids, and liquids. Operational data are the information collected for the installation and operation of the system to include external conditions and operator interface. These data collection standards apply to both capability testing and operational performance testing as described in Section 2.

4.1 Process Data

When performing a WTE evaluation testing program, there are a number of key process data items that should be collected and documented. A suggested list of these items was presented to the Government and subject matter experts at the JDW2E Working Group Meeting on 31 July 2014 in Fort Devens at the US Army Base Camp Integration Laboratory (BCIL) to generate discussion and solicit input. It is recognized that each WTE system may have its own specific data requirements; however, the data items provided in Table 6 should be considered as a minimum.

Table 6 Process data items for collection

Process Data Item	Objective	Description
Waste Characterization	**Capability testing:** Estimate any required deviations from the test standard simulated waste feed recipe for composition, moisture content, and heating value. **Operational performance testing**: Estimate the composition, moisture content, and heating value of the mixed waste materials used for testing.	**Capability testing:** The moisture content and heating value of the test standard simulated waste feed materials are estimated to be 30% and 5300 BTU/lb, respectively (see Appendix C). **Operational performance testing:** The estimated waste composition using the 10 standard waste categories, moisture content (%), and heating value (BTU/lb) for the actual mixed waste materials used for testing.
Waste Processed	Quantify the amount of waste that is processed per unit time so that a batch quantity or throughput can be calculated.	The volume and mass of waste processed, the processing cycle time, and the time between processing cycles.
Emissions	Quantify the amount of emissions (solid, liquid, and gas) generated per unit of time so that a comparison to the amount of waste fed can be calculated.	The volume and mass of effluents (solid, liquid, and gas) emitted during each phase of the operational cycle to include startup, operations, shutdown, and idle time (if applicable).

Table 6 Process data items for collection (continued)

Process Data Item	Objective	Description
Fuel Consumption (if applicable)	Quantify the fuel consumption so that gallons/ton waste processed can be calculated.	The quantity of fuel consumed during each phase of the operational cycle to include startup, operations, shutdown, and idle time (if applicable).
Consumable Usage (if applicable)	Quantify the amount of consumables used so that a quantity/ton of waste processed can be calculated.	The quantity of all consumables used for the process to include water, process chemicals, and other materials.
Electricity Consumption	Quantify the total amount of electricity required to operate the equipment, excluding any electricity produced and returned to the process, so that KWh/ton waste can be calculated.	The electricity required to operate the equipment over the entire cycle. Electricity usage should be measured for each major equipment area (e.g., shredder, primary chamber, pollution abatement equipment) as a peak value and as an average.
Electricity Production (if applicable)	Quantify the total amount of electricity that can be produced from the process so that KWh/ton waste can be calculated.	The electricity produced from the process over the entire cycle that can either be returned to operate the equipment or exported for other uses. The calculated heating value of the waste materials needs to be clearly stated.
Heat or Hot Water Production (if applicable)	Quantify the total amount of heat or hot water produced from the process so that its quantity can be calculated on a per ton of waste basis.	The heat (e.g., facility heating) or hot water produced from the process during each phase of the operational cycle to include startup, operations, shutdown, and idle time (if applicable).
Process Conditions	Collection of critical process data to evaluate ability to operate within control limits.	The process data used to control or operate the equipment (e.g., temperature, pressure). The type of data is specific to each system.

Process data should be collected periodically as applicable by using either automated data logging or manually collected and recorded in a run log. Automated data logging is preferred whenever possible to avoid the risk of manual entry errors. In addition to each run log, a log book should be used to record qualitative observations to include equipment failures and upset conditions, approaches to recover from the failures and upset conditions, and solutions to prevent the failures and upset conditions from reoccurring. Test plan changes should also be captured in the log book to include any changes to the design or operating conditions and any equipment replacements. Every log entry should contain the date, time, and run number (if applicable). This information can become critical during troubleshooting efforts and can assist during capture of lessons learned.

4.2 Sampling/Analytical Data

In order to compare WTE systems to each other and competing technologies such as incineration on a uniform basis, it is important to standardize the sampling and analysis approaches used during demonstration testing. A key challenge is selecting standards that are appropriate for the full range of technologies associated with waste treatment at contingency bases while streamlining the sampling and analysis program to keep costs manageable. One approach is to apply sampling and analysis standards that address regulatory requirements. However, regulatory requirements are site specific and can vary significantly depending on numerous factors including the system selected, location, waste stream, operation duration, emissions profile, and requirements of local regulatory agencies. It is not practical to compile a list of analyses that every regulatory agency could be interested in and perform tests using each of those analyses.

The test standards developed under this task are designed to focus on the following:

1) Understanding key attributes of system performance;

2) Characterizing common emission components that may be of interest to program leadership in evaluating potential for regulatory acceptance; and

3) Establishing common, universal metrics to allow comparisons between systems.

As an initial exercise to determine common regulatory requirements, the team reviewed 4 air emission regulations that could be applicable to WTE technologies:

1) Overseas Environmental Baseline Guidance Document, DOD 4715.05-G);[4]

2) National Ambient Air Quality Standards (NAAQS), 40 Code of Federal Regulations (CFR) part 50;[5]

3) Environmental Protection Agency (EPA) Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Other Solid Waste Incineration Units (OSWI), 40 CFR Part 60;[6] and

4) Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the Incineration of Waste.[7]

Each regulation has its own requirements and approach to measuring emissions. Although the regulations share many of the same target compounds, the acceptable concentration levels are often reported differently. In order to compare the regulations to each other, calculations were made to put the units of measurement on a common basis. This comparison is included in Appendix D and was presented at the JDW2E Working Group Meeting on 31 July 2014. Meeting participants suggested using the EPA OSWI guidelines[6] for the test standards since these guidelines were used in previous Government test programs and were determined to be most applicable to the size of WTE systems evaluated for this study. In addition to considering regulatory requirements, meeting participants suggested considering the sampling and analysis approaches used in previous burn pit and incineration emission studies performed by the Government. By using some of these sampling and analysis approaches, the emissions from WTE systems can more easily be compared to burn pits and incinerators.

Four previous Government studies were selected to determine if any additional sampling and analyses should be included in the test standards. In *Expeditionary Base Camp Waste Incinerator Human Health Risk Assessment, U.S. Army Public Health Command (USAPHC), Health Risk Assessment No. WS.0011774.2-12*,[8] 2 burn pit studies and 1 incineration study (2 incinerators) were referenced in the assessment. One additional test study for a gasification system was selected by the Government for consideration. All 4 studies reviewed for potential applicability to the test standards are shown below:

1) 2011 Initial Performance Test Report Marine Corp Forces Pacific - Camp Smith Micro Auto Gasification System (MAGS);[9]

2) Emissions from Small-Scale Burns of Simulated Deployed U.S. Military Waste;[10]

3) Emissions from Open Burning of Simulated Deployed U.S. Military Waste from Forward Operating Bases;[11] and

4) Reduced Footprint Base Camp - Systems Integration Support, Final Incineration Demonstration/Validation Final Report; prepared by National Defense Center for Energy and Environment (NDCEE), submitted by Concurrent Technologies Corporation (CTC).[12]

A comprehensive list of analyses that were used in the 4 studies was compiled into tables and distributed to the Government for review. Those tables included the type of analysis, target compounds, and example analytical methods. One objective of the review was to determine which analyses were considered critical for the test standards, and which ones, although recommended, could be considered optional if test program funding is limited.

The tables were discussed and adjusted based on input from subject matter experts until consensus was reached. Analyses were selected for the test standards based on EPA OSWI guidelines,[6] ability to use the data in evaluating the performance of the systems, ability to compare results to previous burn pit and incinerator emission testing, and economics (i.e., the value of an analysis compared to its relative cost). The test standards selected based on this evaluation are described in the sections below for air, solids, and liquids.

4.2.1 Air Sampling and Analysis Standard

Table 7 provides the NSRDEC/ARL air sampling and analysis standard, including the analyses for the required test standard and other recommended analyses if those analyses are applicable to the test program and funding is available. The table also includes the studies in which each analysis was performed,[9–12] example analytical methods, and a comparison to the EPA OSWI guidelines.

Table 7 Air sampling and analysis standard

Analysis[1]	Abbrev.	NSRDEC/ARL Test Standard		Ref.	EPA OSWI[2]	Example Methods (EPA Methods)[1]
		Required	Other Recom'd			
Carbon Monoxide	CO	✓		10,12	✓	10, 10A, or 10B
Carbon Dioxide	CO_2	✓		9,10,11,12		3A
Oxygen	O_2	✓		9,10,12		3A
Nitrogen Oxides	NOx	✓		9,10,12	✓	7, 7A, 7C, 7D, or 7E
Sulfur Dioxide	SO_2	✓		10,12	✓	6 or 6C
Total Organic Compounds	TOCs	✓		12		25A
Volatile Organic Compounds	VOCs		✓	10,11,12		0030 and 8260
Semi-Volatile Organic Compounds	SVOCs		✓	12		0010 and 8270
Polycyclic Aromatic Hydrocarbons	PAHs	✓		10,11,12		0010 and 8270
Hydrogen Halides and Halogens						
Bromine	Br_2		✓	12		26A
Chlorine	Cl_2		✓	12		26A
Hydrogen Bromide	HBr		✓	12		26A
Hydrogen Chloride	HCl	✓		9,12	✓	26A
Hydrogen Fluoride	HF		✓	12		26A
Dibenzo-p-dioxins and Dibenzofurans (Dioxins and Furans)						
Polychlorinated	PCDD/Fs	✓		10,11,12	✓	23 (total mass basis)
Polybrominated	PBDD/Fs		✓	10,11		Modified TO-9A
Metals	N/A	✓		10,11,12	✓	29
Particulate Matter (total)	PM	✓		9	✓	5 or 29
PM (2.5µm and 10µm)	$PM_{2.5, 10}$	✓		10,11,12		5, 201A, 202
Visible Emissions/Opacity	N/A	✓		12	✓	9
Moisture Content	N/A	✓				4

[1] See Appendix E for test standard target compounds and additional details on example analytical methods.
[2] EPA OSWI guidelines.[6]

All of the analyses in the EPA OSWI guidelines for air emissions are included in the required test standard. Other required analyses include carbon dioxide (CO_2), oxygen (O_2), total organic compounds (TOCs), polycyclic aromatic hydrocarbons (PAHs), particulate matter (PM) at the 2.5 and 10 micron ($PM_{2.5}$ and PM_{10}) size designation, moisture content, and additional metals. The CO_2 and O_2 are included in the test standard to help gain a better understanding of how the process is performing with respect to complete combustion. In addition, CO_2 and O_2 concentrations may also be required as part of other analytical methods to ensure results are reported on the correct basis (e.g., reported at a specific percent oxygen).

TOCs are included in the required standard to provide valuable information regarding the amount of organics being emitted to the air (e.g., the degree of combustion completion). However, since the TOCs analysis does not provide specific organic compounds, it is recommended to analyze for volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) to better characterize the compounds found in the air emissions. Although the EPA OSWI guidelines do not require these analyses, they should be performed if the budget is available. These analyses will also allow a comparison to the burn pit and incinerator emission data performed in previous Government studies. In order to select the appropriate VOC and SVOC target compounds, it is recommended to review the list of hazardous air pollutants provided in 42 United States Code (USC), Chapter 85, Section 7412. It should be noted that the list is extensive and not all compounds will be applicable to the test program (e.g., herbicides and pesticides are not considered applicable).

Similar to carbon monoxide (CO), which is required by the EPA OSWI guidelines, and TOCs, the PAHs in the test standard will provide useful information regarding combustion effectiveness. If PAHs are found in the stack gas, there could either be incomplete combustion due to bypassing flows or potential reformation.

The only hydrogen halide or halogen analysis the EPA OSWI guidelines require is for hydrochloric acid (HCl). If funding is available, it is recommended to analyze for the other hydrogen halides and halogens listed in EPA method 26A that include bromine (Br_2), chlorine (Cl_2), hydrogen bromide (HBr), and hydrogen fluoride (HF). These compounds may not only be a concern for health reasons, but for their corrosive properties. Knowledge of their presence and concentration in the gas effluent may help determine the adequacy of the materials of construction selected.

It is likely that brominated compounds will not be present in the gas effluent unless there are specific components in the mixed waste stream that contains bromine (e.g., fire retardant materials). For similar reasons, the polybrominated dibenzo-p-dioxins and dibenzofurans analysis are not included in the required test standard.

Analyses for these compounds are only recommended if bromine is likely to be in the mixed waste and funding is available to perform the analysis. This is not to be confused with the polychlorinated dibenzo-p-dioxins and dibenzofurans (commonly known as "dioxins" and "furans") that are included in the required test standard.

The only metals analyses required by the EPA OSWI guidelines are cadmium (Cd), lead (Pb), and mercury (Hg). Due to the relatively low incremental cost of measuring additional metals in EPA Method 29, the full suite of metals (18) listed in this method were added to the required test standard.

The EPA OSWI guidelines require PM analyses but do not require measurement of specific size particles. Due to the health concerns specifically with the smaller particles, the test standard includes $PM_{2.5}$ and PM_{10} as well as total PM in accordance with the OSWI guidelines. It is anticipated that the total PM can be measured with the same equipment used to collect the $PM_{2.5}$ and PM_{10} with minimal (if any) additional cost.

Although moisture content is not specifically required in the EPA OSWI guidelines, it may be required as part of other methods. For example, many species are typically reported on a dry basis. Without moisture content measured, it would not be possible to report the results on a dry basis.

4.2.2 Solid Residue and Liquid Effluent Sampling and Analysis Standard

The test standard for solid and liquid effluents were developed using a similar methodology to the air emissions. However, the EPA OSWI guidelines focus on air emissions and do not provide specific guidance on the solid and liquid emissions. In addition, the NDCEE incinerator study[12] was the only one reviewed for this task to characterize solid residues. None of the studies reviewed for this task evaluated liquid emissions (burn pits and incinerators typically do not have liquid effluent streams). Therefore, the primary focus to select a test standard was to use sampling and analyses methods that characterize the effluent sufficiently to determine potential disposal requirements and options (i.e., if it might be classified as a hazardous waste).

To help select the test standard for the solid and liquid effluents, input was solicited from the JDW2E permitting subject matter expert via email.[13] Additional EPA guidance was used that included the following:

- EPA Guidance for the Sampling and Analysis of Municipal Waste Combustion Ash for the Toxicity Characteristic;[14]

- EPA Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Wastes; A Guidance Manual;[15]
- 40 CFR Part 261, Subpart C, Characteristics of Hazardous Waste; and
- EPA SW846, Chapter 7.

In accordance with 40 CFR Part 261, Subpart C, a waste is hazardous if it exhibits any of the 4 characteristics: ignitability; corrosivity; reactivity; or toxicity. A summary description of each of these characteristics is shown below.

Ignitability: Ignitable wastes create fires under certain conditions, are spontaneously combustible, or have a flash point less than 60 °C (140 °F).

Corrosivity: Corrosive wastes are acids or bases (pH less than or equal to 2 or greater than or equal to 12.5, respectively) that are capable of corroding metal containers, such as storage tanks, drums, and barrels.

Reactivity: Reactive wastes are unstable under “normal” conditions. The EPA relies entirely on a descriptive, prose definition of reactivity. There are no test methods. The regulation in 40 CFR 261.23 defines reactive wastes to include wastes that have any of the following properties: 1) readily undergo violent chemical change; 2) react violently or form potentially explosive mixtures with water; 3) generate toxic fumes when mixed with water or, in the case of cyanide- or sulfide-bearing wastes, when exposed to mild acidic or basic conditions; 4) explode when subjected to a strong initiating force; 5) explode at normal temperatures and pressures; or 6) fit within the Department of Transportation's forbidden explosives, Class A explosives, or Class B explosives classifications.

Toxicity: Toxic wastes are harmful or fatal when ingested or absorbed. When toxic wastes are disposed of on land, contaminated liquid may drain (leach) from the waste and pollute ground water. Toxicity is defined through a laboratory procedure called the toxicity characteristic leaching procedure (TCLP), which is designed to simulate the leaching a waste will undergo if disposed of in a sanitary landfill.

In addition to these federal hazardous waste identification rules, local agencies may have additional or more stringent requirements. It is not practical to include all possible requirements from local agencies in the test standard. Therefore, the recommended test standard for solid residues and liquid effluents rely primarily on the federal guidelines with a few additions as shown in Table 8. These recommendations were reviewed by Government subject matter experts and consensus was reached. All of the relevant analyses from the guidance documents shown above are included in the test standard. Additional analyses include polychlorinated dioxins and furans and total organic carbon (TOC).

Table 8 Solid and liquid sampling and analysis standard

Analysis[1]	Abbrev.	NSRDEC/ARL Test Standard		Ref.	EPA Guidance[2]	Example Methods (EPA Methods)[1]
		Required	Other Recom'd.			
TCLP Volatile Organic Compounds	TCLP VOCs	✓		12	✓	1311 and 8260 (TCLP compounds only)
Volatile Organic Compounds	VOCs		✓	13		8260 (additional compounds)
TCLP Semi-Volatile Organic Compounds	TCLP SVOCs	✓		12	✓	1311 and 8270 (TCLP compounds only)
Semi-Volatile Organic Compounds	SVOCs		✓	13		8270 (additional compounds)
Dibenzo-p-dioxins and Dibenzofurans (Dioxins and Furans)						
Polychlorinated	PCDD/Fs	✓		13		1613
Polybrominated	PBDD/Fs		✓	13		Modified (1613 and TO-9A)
Total Organic Carbon	TOC	✓		12		9060
TCLP Metals	N/A	✓		12	✓	1311 and 6010 7470 (Mercury only)
Metals	N/A		✓	13		6010 7470/7471 (Mercury only)
Corrosivity	pH	✓		12	✓	9045
Ignitability	N/A	✓		12	✓	1010
Reactivity	N/A	✓			✓	40 CFR §261.23

[1] See Appendix F for recommended target compound lists and additional details on example analytical methods.

[2] EPA Guidance for the Sampling and Analysis of Municipal Waste Combustion Ash for the Toxicity Characteristic;[14] EPA Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Wastes; A Guidance Manual;[15] and 40 CFR Part 261, Subpart C, *Characteristics of Hazardous Waste*.

The polychlorinated dioxins and furans analysis is included in the test standard per J2W2E subject expert recommendations.[13] Similar to the air emissions test standard, polybrominated dioxins and furans analysis is recommended only if bromine compounds are likely to be in the mixed waste and funding is available to perform the analysis. The TOC analysis is added to provide a comparison to the previous incineration emission testing[12] and to collect additional performance data from the system.

The test standard includes only the VOC and SVOC contaminants for the toxicity characteristic listed in 40 CFR Part 261, Subpart C, Table 1 and EPA SW846, Chapter 7, Table 7-1. If funding is available and there is a need to identify additional VOC and SVOC compounds, those compounds should be selected from the lists provided in EPA methods 8260 and 8270. It should be noted that some compounds listed in those methods may not be applicable (e.g., pesticides and herbicides are not considered applicable).

Similar to the VOCs and SVOCs, the metals analyses selected for the test standard include only those listed as part of the TCLP. If funding is available and the need exists, additional metals can be analyzed as listed in EPA method 6010.

Appendices D (air emissions) and E (solid residue and liquid effluent) provide a comprehensive list of potential analyses to be performed as part of the test standard, a reference to previous waste treatment studies reviewed for this task[9–12] that also performed those analyses, suggestions from the JDW2E subject matter expert,[13] a more detailed discussion of the example analytical methods along with Internet links and a list of potential target compounds for the categorical analyses in the test standard (e.g., polychlorinated dioxins and furans, VOCs, SVOCs, and PAHs).

It should be noted that each system configuration is different; therefore, appropriate sampling and analysis approaches could vary. The analytical methods shown in the test standard tables should be viewed as examples only. Details regarding the sampling and analysis approaches and methods used to collect and perform the analyses should be specified in each sampling and analysis plan.

4.3 Operational Data

In addition to the process data collected to evaluate the performance of a system, data should be collected to gain a better understanding of the capabilities and requirements from an operational perspective. This information can be used to identify areas for future improvement and determine the most suitable application for use of the system. For example, if the system requires specially trained contract operators, it may be more suitable for some installations than others.

A session was held with the Government and subject matter experts at the JDW2E Working Group Meeting on 1 August 2014 to generate discussion and solicit input regarding the desired operational data that should be collected during a demonstration test program. It is recognized that each WTE system may have its own specific data requirements; however, the data items summarized in Table 9 should be considered as a minimum. Since most of these data items are qualitative and descriptive in nature, the information should be captured in log books, and then consolidated as part of a discussion in the final report.

Table 9 Operational data for collection

Operational Data Item	Objective	Description
Installation/ Demobilization	Identify the requirements for installation and demobilization of the equipment and compare the planned (design) verses actual performance.	Collect data regarding installation and demobilization activities to include weight and dimension of modules requiring placement, equipment and personnel required, site preparation work, any specialized equipment needed, and duration.
Permitting	Document the required process to permit the equipment (if required) at the test location.	Describe the permitting process to include any sampling and analysis requirements, operation restrictions, data collection/submission requirements, and estimated time required to obtain the permit.
Environmental Conditions	Document the external conditions in which the system was operated.	Collect data regarding the environmental conditions observed during testing to include temperature, humidity, and atmospheric pressure (altitude).
Safety	Identify any potential safety concerns not previously identified in the safety reviews.	Provide a description of any potential safety concerns with respect to operational personnel and surrounding area personnel that were not already identified during safety reviews (e.g., job hazards analysis, hazard operability study).
Number of Operators	Identify the number of personnel required to operate and maintain the equipment.	Describe the number of personnel required to perform each task (e.g., feed preparation, startup, normal operation, shut down, maintenance), and the observed durations for each task.
Operator Skills and Training	Identify the skill level and training requirements of the personnel required to operate and maintain the equipment.	Describe the skill level and training required for each personnel that perform individual tasks (e.g., feed prep, startup, normal operation, shutdown, maintenance).
Specialty Equipment	Identify any specialty equipment needed to operate and maintain the equipment.	Describe any specialty equipment such as tools, machinery, and personal protective attire that are needed to operate and maintain the equipment.
Operational and Down Time	Document the observed operational time verses planned and unplanned downtime.	Record times during startup, normal operations, and shutdown to include feed preparation and handling times and residue removal times. Collect times for planned and unplanned maintenance activities along with a description of those activities.
Noise	Compare noise levels to industry standards.	Measure noise levels at various locations and times during operations.
Odor	Document observed odors from the process during operation.	Qualitatively assess any odors generated from the equipment during processing.
Residual Disposal	Identify the requirements for collecting and disposing solid and liquid process effluents.	Describe the operational requirements for removing, collecting, storing, and disposing solid and liquid wastes generated by the process. Include any additional waste treatment that may be required prior to disposal.
Video/Photo	Use visual media to augment test report narrative.	Collect video and still photos of key operational and maintenance activities to include the raw waste fed into the system and process effluents. Capture video/photos of stack (i.e., smoke) and any potential heat signature equipment during operation.
Post Test Inspections	Identify any wear or component fatigue that may have resulted prematurely from the test program.	Between test runs and at the conclusion of testing, inspect system components for corrosion or fatigue/failure. Collect measurements as appropriate.

5. Test Program Documentation

Each system and test program is unique and will have its own objectives, requirements, stakeholders, and end-product expectations. Likewise, each program will have its own program documentation to support the test planning as well as capture test results. The test standards do not require a specific structure or prescriptive format for any of the test documentation. However, there are key elements that should be provided in the test documents to allow comparison between test programs and to ensure a minimum level of information is captured and can be archived for future reference. It is recommended that at a minimum there is a test plan, sampling and analysis plan, and a final report. The information that should be captured in each document is provided in the sections below.

5.1 Test Plan

The purpose of a test plan is to ensure that all participants are in agreement and stakeholder expectations are established and documented prior to testing. It also ensures that an adequate plan is in place to capture and document the necessary data resulting from the test program. At a minimum, the test plan should answer the 5 W's as shown in table 10.

Table 10 Test plan content

5 W's	Information to Include in a Test Plan
Who	All organizations involved and their roles and responsibilities.
What	Description of the system, test setup, and planned tests to include feed materials, test runs, process conditions, information that is to be collected, disposition of process wastes, and expectations for the equipment based on vendor specifications or guarantees.
Where	Site location.
When	Anticipated schedule with durations if exact dates are not known.
Why	General purpose of the test program and what the data collected will be used for.

The test plan should include a process description including a block flow diagram with sufficient information to present how the system is configured, what the inputs and outputs are, and the general operating philosophy. Operating procedures should also be provided to identify the required operator interface, controls and automation, and any special training requirements.

It is recommended that test run templates are provided in the test plan that will be used to capture process monitoring and operational data outlined in Tables 6 and 9.

If any data are to be captured using automated data logging, a note should be provided in the templates. This will ensure that all participants clearly understand the data collection expectations prior to testing and will minimize the risk of missing data collection opportunities during the testing.

5.2 Sampling and Analysis Plan

As a standalone document, or as part of the test plan, the sampling and analysis plan should contain all information related to what samples will be collected; how those samples will be collected, stored, shipped to and analyzed at a laboratory; how the results will be reported; and the quality assurance approach. It is recommended to include a block flow diagram with all of the sampling locations identified. The information in Tables 7 and 8 should be updated to include any additional analyses that will be performed, the analytical methods that will be used, and any modification to the equipment and/or analytical method that may be required to collect and analyze the samples.

5.3 Final Report

The final report should present the data collected as described in the test plan and sampling and analysis plan. In addition to the information from Tables 6–9, a narrative summary of the results, conclusions, lessons learned, and recommendations should be provided. Any calculations used during data analysis to develop the conclusions should be explained in sufficient detail that the results could be recreated.

For the air emission analyses, results should be compared to the EPA guideline for the OSWI.[6] For solid and liquid effluents, the analytical results should be compared to the EPA characteristics of hazardous wastes (40 CFR Part 261, Subpart C). For both comparisons, concentrations should be reported in the same units that are used by the EPA (e.g., ppmdv, µg/dscm, mg/L).

6. Discussion on Impact to Potential Technologies

As mentioned previously, one of the challenges of preparing test standards is that each system and test program may differ significantly. The approach that may work well for one system may not be appropriate for another. Not all situations can be addressed in a test standard, but the impacts the test standard may have on some of the common technology types can be discussed. The largest challenge is the determination of “representative” samples for different systems so they can be compared to each other. For example, the sampling and analysis approach used for continuous systems may be significantly different than batch systems. Continuous systems have a distinct startup period, steady-state, and shutdown period. Samples can be collected during steady-state for these systems to determine its performance during the majority of its operation. For batch processes, there is no true steady-state. There will typically be a period where moisture is drawn off the waste followed by gas evolution from the combustion/pyrolysis reactions which will vary over time. A very different sampling approach may be needed for batch systems.

A recommendation to address this scenario is provided in the next section. However, there are many approaches to collecting representative samples that can vary significantly with different systems. It is imperative that the methodology used to determine representative samples, and the approach used to collect them, are detailed in the test plan and sampling and analysis plan.

7. Recommendations

Throughout the preparation of the test standards, a number of recommendations were developed to assist users during their implementation of these standards. These recommendations are grouped into several topic areas as shown below:

1) Simulated Test Standard Waste verses Actual Base Waste

    a) Recommend size reducing and mixing the simulated waste feed so that it can be fed into the system in a way as representative as practical to actual base operations. For example, if the equipment is intended to be loaded using small trash bags, the simulated waste should be size reduced and mixed so that it can be packaged in a similar fashion prior to processing.

    b) Recommend preparing the simulated waste feed ahead of time by size-reducing and mixing the long shelf-life components (e.g., cardboard, plastics, textiles) together in bulk first, then just prior to feeding into the system add the appropriate amount of liquids (in accordance with the simulated food recipe portion) for each batch or continuous run. This will allow for a larger buffer of feed materials and minimize the time required for size reducing and mixing prior to each batch or continuous run.

    c) Determine if the system being evaluated has known or suspected issues with processing a specific waste component and prepare an additional challenge recipe with that component to evaluate its performance. One example could be with a specific plastic type that a system is suspected to have difficulty processing.

d) Material handling evaluations are better suited for operational performance testing (using actual base waste materials) instead of during capability testing (using simulated feed recipes).

2) Representative Sampling and Analysis for Continuous verses Batch Systems

a) Air emissions sampling as part of the test standard for continuous systems should be performed during steady-state operations.

b) Air emissions sampling as part of the test standard for batch systems should be collected during peak gas evolution periods. Additional sampling should also be performed earlier and later during the processing cycle when smaller quantities of gas are being generated and gas composition(s) may be different. Workup testing may be needed to identify when these periods occur and how they are determined (e.g., using temperature profiles to determine when the majority of water has been removed and pyrolysis/combustion begins).

3) Potential Additional Sampling and Analysis

a) Review local regulatory requirements for the test program and/or potential deployment sites and add relevant analyses to the test standards.

b) During operational performance testing (using actual base wastes), determine if there are any specific compounds in that waste stream that could result in additional emission concerns (e.g., PCBs, pesticides, herbicides) and augment the sampling and analysis approach to include those target compounds.

c) Determine if the incremental cost of performing additional analyses (or adding target compounds) is sufficiently low to justify the value of performing those analyses. Examples could include additional metals analyses or VOC/SVOC target compounds that may be of interest.

d) The test standards do not include ambient air monitoring. These analyses can vary significantly depending on wind speeds and stack height; and the results may not accurately represent the performance of each system (too many external factors). It is recommended to perform these tests once the Government is closer to selecting a system and the tests can be performed in a representative environment to that in which the system is intended for deployment.

4) Workup Testing

   a) In addition to normal systemization and workup testing to ensure the equipment is performing adequately, it is recommended to perform workup testing for the sampling and analysis approaches. This will be beneficial for not only operator practice, but will ensure the sampling and analysis equipment and procedures are adequate.

5) Potential Additional Safety Evaluations

   a) The test standards do not include formal safety evaluations other than documented observations during testing. However, it is important for any test program to include job hazards analyses and/or hazard operability studies. It is recommended that each test program includes these analyses prior to operations.

   b) The test standards do not include human factors evaluations. It is recommended that once the Government is closer to selecting a system and has a better understanding of the personnel resources that will be required to perform the operations and maintenance activities, an assessment be performed.

6) Warrantied/Guaranteed Performance Evaluation

   a) In some test and evaluation programs, the vendor may provide a performance guarantee. In those situations, the program should evaluate the extent that the equipment tested met those performance guarantees.

   b) If performance guarantees are not achieved, the program should determine what changes are required to achieve the desired/expected performance.

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Appendix A. Simulated Waste Feed Examples and Estimated Costs

Simulated Waste Feed Examples and Estimated Costs

Standard Recipe Waste Category	Wt %	Lbs per 1-ton Batch	Description of Example Simulated Material	Estimated Cost ($)
Cardboard	**15%**	**300**		**$ 608**
Item 1	15%	300	Uline 11x17", 1/8" inch thick, corrugated pads model no. S3585 (~1900 sheets)	$ 608
Mixed paper	**10%**	**200**		**$ 476**
Item 1	10%	20	Costco Copy Paper, Letter, 20lb, 92-Bright, 5,000ct (one 20-lb box)	$ 36
Item 2	90%	180	Chinet® Beige 5-Compartment Molded Fiber Cafeteria Tray - 8.5" x 10.5" (~2500 trays)	$ 440
Food waste	**32%**	**640**		**$ 162**
Item 1	21%	133	Gravy Train® Beef Dry Dog Food (~four 35-lb bags)	$ 120
Item 2	6%	40	Crisco Pure Canola Oil, 128 Ounce (~5 containers)	$ 42
Item 3	73%	467	Water (~56 gallons)	$ -
Plastic (total)	**15%**	**300**		**$ 1,338**
#1 PET	6.0%	120	12 oz. PET Clear Plastic Juice Bottle Base by Carefree - 160 per case; no lids (~1280 bottles)	$ 720
#2 HDPE	2.7%	54	12 oz. HDPE Clear Plastic Juice Bottle Base by Carefree - 500 per case; no lids (~900 bottles)	$ 250
#3 PVC	0.9%	18	1-1/2 in. x 10 ft. PVC Sch. 40 DWV Plain End Pipe (~1.7 needed)	$ 11
#4 LDPE	2.7%	54	Fortune Plastics DuraRoll LDPE 30 Gallon Waste Can Liner, Star Seal, Clear, 0.19 Mil, 36" x 30" (~5 cases of 250 ea.)	$ 145
#5 PP	0.3%	6	Choice-Pac 3D-1429T Polypropylene Bowl, White, Medium, 24-Ounce (~100 bowls)	$ 31
#6 PS	1.8%	36	*See two items below*	*$ 130*
Item 1	0.5%	11	White Heavy Weight PolySty Plastic Fork - 1000 per case (~831 forks)	$ 34
Item 2	1.3%	25	Dart Container 95HT3 Carryout Food Container, Foam Hinged 3-Compartment, 9-1/2 x 9-1/4 x 3, (~2355 containers)	$ 96
#7 Other	0.6%	12	Verbatim 700 MB 52x 80 Minute Branded Recordable Disc CD-R - 100-Disc Spindle, FFP 97458 (~3 spindles)	$ 51
Wood	**14%**	**280**		**$ 78**
Item 1	14%	280	2 in. x 4 in. x 96 in. Prime Kiln Dried Heat-Treated Untreated SPF Stud (~26 2x4s)	$ 78
Metals	**6%**	**120**		**$ 836**
Aluminum	2.2%	43.2	Amerimax Home Products 66006 6-In x 50-Ft .0078-In Thickness Aluminum Roll Valley Versa Flashing (~15 rolls)	$ 308
Ferrous	3.6%	72	*See two items below*	*$ 475*
Item 1	2.7%	54	Freund 4 oz Unlined Tin-Plated Steel Open Top Cans (202 Lid) - Dry Pack (~102 cans/lids)	$ 439
Item 2	0.9%	18	Grip-Rite #8 x 3-1/2 in. 16D Bright Steel Smooth Shank Common Nails - 30 lb. Pack (~0.6 boxes)	$ 36
Non-ferrous	0.2%	4.8	SAS Safety AAS 1/4" Brass Compression Union Steel to Steel (~24 each)	$ 54
Glass	**1%**	**20**		**$ 84**
Item 1	1%	20	Clear Glass Woozy Bottles, 12 Oz (~30 bottles)	$ 84
Rubber & neoprene	**1%**	**20**		**$ 60**
Item 1	1%	20	International Mulch #rm16bk-mw 16lb Black Rubberific Mulch (~1.25 bags)	$ 60
Textile	**3%**	**60**		**$ 101**
Item 1	3%	60	All Rags Cotton blend t-shirt material, light to medium weight, no color - 50 lbs box (~1.2 boxes)	$ 101
Misc. waste/other	**3%**	**60**		**$ 263**
Item 1	2.1%	42	Nestle Pure Life Purified Water, 16.9-ounce plastic bottles (~40 bottles)	$ 18
Item 2	0.3%	6	Maxell LR6 AA Cell 48 Pack Box Battery (723443) (~111 batteries)	$ 45
Item 3	0.3%	6	Cyalume ChemLight Military Grade Chemical Light Sticks, Yellow, High Intensity, 6" Long, 30 Min. Duration (~102 sticks)	$ 166
Item 4	0.3%	6	Dust-Off Compressed Gas Duster (~6 canisters)	$ 34
TOTAL		**2000**		**$ 4,005**

Appendix B. Estimated Heat and Moisture Content for the Simulated Waste

Estimated Heat and Moisture Content for the Simulated Waste Standard Recipe

Simulated Waste Component(s) [See Table 3-3 and App. B]	Weight Percent (%)	Lbs Per Ton of Waste	Moisture content	Heat Content[1] (Dry Basis) (Btu/lb)	Heat Content (Btu)	Moisture Content Reference and Assumptions	Heat Content Reference and Assumptions
Corrugated Cardboard	15%	300	10.5%	8,250	2,215,125	Ref. 16; Range between 9 and 12%	Ref. 17
Paper	10%	200	4.5%	3,350	639,850	Ref. 18; Xerox® target moisture content	Ref. 17
Food waste (total)	32%	640	75%	6,100	992,884	See below	See below
Dog food	6.7%	133	8%	2,252	276,241	Internet search; Assumed 8% moisture	Internet search; Assumed 284 kcal/8 oz. cup
Vegetable oil	2.0%	40	0%	17,832	713,280	Assumed moisture content is negligible	Ref. 19; Assumed canola oil
Water	23.3%	467	100%	-	-	NA	NA
Plastic (total)	15%	300	0%	13,233	3,969,984	See below	See below
#1 PET	6.0%	120	0%	10,250	1,230,000	Assumed moisture content is negligible	Ref. 17
#2 HDPE	2.7%	54	0%	19,000	1,026,000	Assumed moisture content is negligible	Ref. 17
#3 PVC	0.9%	18	0%	8,250	148,500	Assumed moisture content is negligible	Ref. 17
#4 LDPE	2.7%	54	0%	12,050	650,700	Assumed moisture content is negligible	Ref. 17
#5 PP	0.3%	6	0%	19,000	114,000	Assumed moisture content is negligible	Ref. 17
#6 PS	1.8%	36	0%	17,800	640,800	Assumed moisture content is negligible	Ref. 17
#7 Other	0.6%	12	0%	13,332	159,984	Assumed moisture content is negligible	Ref. 20; Assumed polycarbonate
Wood	14%	280	10%	8,260	2,081,520	Ref. 21; Estimated equilibrium moisture content	Ref. 20; Assumed white pine
Metals (total)	6%	120	0%	-	-	See below	See below
Aluminum	2.2%	43.2	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Ferrous	3.6%	72	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Non-ferrous	0.2%	4.8	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Glass	1%	20	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Rubber/Neoprene	1%	20	0%	14,025	280,500	Assumed moisture content is negligible	Ref. 20; Assumed car tires
Textile	3%	60	9%	7,937	433,360	Ref. 22; Estimated equilibrium moisture content	Ref. 20; Assumed cotton shirts
Misc./Other	3%	60	70%	1,025	18,393	Estimated based on simulated components	Estimated based on simulated components
Totals	**100%**	**2000**	**29.7%**		**10,628,253**		

5,314	**Btu/lb waste (wet basis)**
10.6	**MMBtu/ton waste (wet basis)**
29.7%	**Moisture Content**

[1] Quantity reported as the Higher Heating Value (HHV).

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Estimated Heat and Moisture Content for the Simulated Waste Cardboard/Paper Challenge Recipe

Simulated Waste Component(s) [See Table 3-3 and App. B]	Weight Percent (%)	Lbs Per Ton of Waste	Moisture content	Heat Content[1] (Dry Basis) (Btu/lb)	Heat Content (Btu)	Moisture Content Reference and Assumptions	Heat Content Reference and Assumptions
Corrugated Cardboard	19%	380	10.5%	8,250	2,805,825	Ref. 16; Range between 9 and 12%	Ref. 17
Paper	38%	760	4.5%	3,350	2,431,430	Ref. 18; Xerox® target moisture content	Ref. 17
Food waste (total)	18%	360	75%	4,175	382,289	See below	See below
Dog food	3.7%	75	8%	2,252	155,386	Internet search; Assumed 8% moisture	Internet search; Assumed 284 kcal/8 oz. cup
Vegetable oil	1.1%	23	0%	17,832	401,220	Assumed moisture content is negligible	Ref. 19; Assumed canola oil
Water	13.1%	262	100%	-	-	NA	NA
Plastic (total)	8%	160	0%	13,233	2,117,325	See below	See below
#1 PET	3.2%	64	0%	10,250	656,000	Assumed moisture content is negligible	Ref. 17
#2 HDPE	1.4%	29	0%	19,000	547,200	Assumed moisture content is negligible	Ref. 17
#3 PVC	0.5%	10	0%	8,250	79,200	Assumed moisture content is negligible	Ref. 17
#4 LDPE	1.4%	29	0%	12,050	347,040	Assumed moisture content is negligible	Ref. 17
#5 PP	0.2%	3	0%	19,000	60,800	Assumed moisture content is negligible	Ref. 17
#6 PS	1.0%	19	0%	17,800	341,760	Assumed moisture content is negligible	Ref. 17
#7 Other	0.3%	6	0%	13,332	85,325	Assumed moisture content is negligible	Ref. 20; Assumed polycarbonate
Wood	8%	160	10%	8,260	1,189,440	Ref. 21; Estimated equilibrium moisture content	Ref. 20; Assumed white pine
Metals (total)	3%	60	0%	-	-	See below	See below
Aluminum	1.1%	21.6	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Ferrous	1.8%	36	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Non-ferrous	0.1%	2.4	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Glass	1%	20	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Rubber/Neoprene	1%	20	0%	14,025	280,500	Assumed moisture content is negligible	Ref. 20; Assumed car tires
Textile	2%	40	9%	7,937	288,907	Ref. 22; Estimated equilibrium moisture content	Ref. 20; Assumed cotton shirts
Misc./Other	2%	40	70%	1,025	12,262	Estimated based on simulated components	Estimated based on simulated components
Totals	**100%**	**2000**	**19.5%**		**9,682,294**		

4,841	**Btu/lb waste (wet basis)**
9.7	**MMBtu/ton waste (wet basis)**
19.5%	**Moisture Content**

[1] Quantity reported as the Higher Heating Value (HHV).

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Estimated Heat and Moisture Content for the Simulated Waste
Food Challenge Recipe

Simulated Waste Component(s) [See Table 3-3 and App. B]	Weight Percent (%)	Lbs Per Ton of Waste	Moisture content	Heat Content[1] (Dry Basis) (Btu/lb)	Heat Content (Btu)	Moisture Content Reference and Assumptions	Heat Content Reference and Assumptions
Corrugated Cardboard	11%	220	10.5%	8,250	1,624,425	Ref. 16; Range between 9 and 12%	Ref. 17
Paper	7%	140	4.5%	3,350	447,895	Ref. 18; Xerox® target moisture content	Ref. 17
Food waste (total)	51%	1020	75%	8,712	2,259,972	See below	See below
Dog food	10.6%	212	8%	2,252	440,259	Internet search; Assumed 8% moisture	Internet search; Assumed 284 kcal/8 oz. cup
Vegetable oil	3.2%	64	0%	17,832	1,136,790	Assumed moisture content is negligible	Ref. 19; Assumed canola oil
Water	37.2%	744	100%	-	-	NA	NA
Plastic (total)	11%	220	0%	13,233	2,911,322	See below	See below
#1 PET	4.4%	88	0%	10,250	902,000	Assumed moisture content is negligible	Ref. 17
#2 HDPE	2.0%	40	0%	19,000	752,400	Assumed moisture content is negligible	Ref. 17
#3 PVC	0.7%	13	0%	8,250	108,900	Assumed moisture content is negligible	Ref. 17
#4 LDPE	2.0%	40	0%	12,050	477,180	Assumed moisture content is negligible	Ref. 17
#5 PP	0.2%	4	0%	19,000	83,600	Assumed moisture content is negligible	Ref. 17
#6 PS	1.3%	26	0%	17,800	469,920	Assumed moisture content is negligible	Ref. 17
#7 Other	0.4%	9	0%	13,332	117,322	Assumed moisture content is negligible	Ref. 20; Assumed polycarbonate
Wood	10%	200	10%	8,260	1,486,800	Ref. 21; Estimated equilibrium moisture content	Ref. 20; Assumed white pine
Metals (total)	4%	80	0%	-	-	See below	See below
Aluminum	1.4%	28.8	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Ferrous	2.4%	48	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Non-ferrous	0.2%	3.2	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Glass	1%	20	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Rubber/Neoprene	1%	20	0%	14,025	280,500	Assumed moisture content is negligible	Ref. 20; Assumed car tires
Textile	2%	40	9%	7,937	288,907	Ref. 22; Estimated equilibrium moisture content	Ref. 20; Assumed cotton shirts
Misc./Other	2%	40	70%	1,025	12,262	Estimated based on simulated components	Estimated based on simulated components
Totals	**100%**	**2000**	**42.1%**		**8,629,159**		

4,315	**Btu/lb waste (wet basis)**
8.6	**MMBtu/ton waste (wet basis)**
42.1%	**Moisture Content**

[1] Quantity reported as the Higher Heating Value (HHV).

References:

16. CargoHandbook com; http://www.cargohandbook.com/index.php/Cardboard.

17. Methodology for Allocating Municipal Solid Waste to Biogenic/Non-Biogenic Energy; U.S. Energy Information Administration (EIA); Office of Coal, Nuclear, Electric, and Alternate Fuels, Washington, DC., May 2007; http://www.eia.gov/totalenergy/data/monthly/pdf/historical/msw.pdf.

18. Xerox®; http://www.xerox.com/downloads/usa/en/s/supp_lib_Helpful_Facts_About_Paper.pdf.

19. Anastasios Argeros, Dan Pincus, Zachary Shinar, and Andrea Sultenfuss, "Heat of Combustion of Oils", April 1998.

20. V. Babrauskas, "Heat of Combustion and Potential Heat," in Heat Release in Fires, V. Babrauskas, S.J. Grayson, eds., Chapter 8, pp. 207-223, Elsevier Applied Science, London, 1992; http://fire.nist.gov/bfrlpubs/fire92/PDF/f92030.pdf.

21. William T. Simpson, Conrad Lumber Company, Wood Handbook, Chapter 12, "Drying and Control of Moisture Content and Dimensional Changes"; http://www.conradlumberco.com/pdfs/ch12_Drying_Control_of_Moisture.pdf.

22. Kaisa Bengtsson, Kathrine Segel, Henrietta Havsteen-Mikkelsen, and Tim Padfield, "The Physics of Drying Cloth"; http://www.conservationphysics.org/wetstuff/wetstuff01.php.

Estimated Heat and Moisture Content for the Simulated Waste

Plastic Challenge Recipe

Simulated Waste Component(s) [See Table 3-3 and App. B]	Weight Percent (%)	Lbs Per Ton of Waste	Moisture content	Heat Content[1] (Dry Basis) (Btu/lb)	Heat Content (Btu)	Moisture Content Reference and Assumptions	Heat Content Reference and Assumptions
Corrugated Cardboard	10%	200	10.5%	8,250	1,476,750	Ref. 16; Range between 9 and 12%	Ref. 17
Paper	6%	120	4.5%	3,350	383,910	Ref. 18; Xerox® target moisture content	Ref. 17
Food waste (total)	21%	420	75%	4,588	490,056	See below	See below
Dog food	4.4%	87	8%	2,252	181,283	Internet search; Assumed 8% moisture	Internet search; Assumed 284 kcal/8 oz. cup
Vegetable oil	1.3%	26	0%	17,832	468,090	Assumed moisture content is negligible	Ref. 19; Assumed canola oil
Water	15 3%	306	100%	-	-	NA	NA
Plastic (total)	44%	880	0%	13,233	11,645,286	See below	See below
#1 PET	17.6%	352	0%	10,250	3,608,000	Assumed moisture content is negligible	Ref. 17
#2 HDPE	7.9%	158	0%	19,000	3,009,600	Assumed moisture content is negligible	Ref. 17
#3 PVC	2.6%	53	0%	8,250	435,600	Assumed moisture content is negligible	Ref. 17
#4 LDPE	7.9%	158	0%	12,050	1,908,720	Assumed moisture content is negligible	Ref. 17
#5 PP	0.9%	18	0%	19,000	334,400	Assumed moisture content is negligible	Ref. 17
#6 PS	5.3%	106	0%	17,800	1,879,680	Assumed moisture content is negligible	Ref. 17
#7 Other	1.8%	35	0%	13,332	469,286	Assumed moisture content is negligible	Ref. 20; Assumed polycarbonate
Wood	9%	180	10%	8,260	1,338,120	Ref. 21; Estimated equilibrium moisture content	Ref. 20; Assumed white pine
Metals (total)	4%	80	0%	-	-	See below	See below
Aluminum	1.4%	28.8	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Ferrous	2.4%	48	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Non-ferrous	0.2%	3.2	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Glass	1%	20	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Rubber/Neoprene	1%	20	0%	14,025	280,500	Assumed moisture content is negligible	Ref. 20; Assumed car tires
Textile	2%	40	9%	7,937	288,907	Ref. 22; Estimated equilibrium moisture content	Ref. 20; Assumed cotton shirts
Misc./Other	2%	40	70%	1,025	12,262	Estimated based on simulated components	Estimated based on simulated components
Totals	**100%**	**2000**	**19.5%**		**16,075,108**		

8,038	**Btu/lb waste (wet basis)**
16.1	**MMBtu/ton waste (wet basis)**
19.5%	**Moisture Content**

[1] Quantity reported as the Higher Heating Value (HHV).

References:

16. CargoHandbook.com; http://www.cargohandbook.com/index.php/Cardboard.

17. Methodology for Allocating Municipal Solid Waste to Biogenic/Non-Biogenic Energy; U.S. Energy Information Administration (EIA); Office of Coal, Nuclear, Electric, and Alternate Fuels, Washington, DC., May 2007; http://www.eia.gov/totalenergy/data/monthly/pdf/historical/msw.pdf.

18. Xerox®; http://www.xerox.com/downloads/usa/en/s/supp_lib_Helpful_Facts_About_Paper.pdf.

19. Anastasios Argeros, Dan Pincus, Zachary Shinar, and Andrea Sultenfuss, "Heat of Combustion of Oils", April 1998.

20. V. Babrauskas, "Heat of Combustion and Potential Heat," in Heat Release in Fires, V. Babrauskas, S.J. Grayson, eds., Chapter 8, pp. 207-223, Elsevier Applied Science, London, 1992; http://fire.nist.gov/bfrlpubs/fire92/PDF/f92030.pdf.

21. William T. Simpson, Conrad Lumber Company, Wood Handbook, Chapter 12, "Drying and Control of Moisture Content and Dimensional Changes"; http://www.conradlumberco.com/pdfs/ch12_Drying_Control_of_Moisture.pdf.

22. Kaisa Bengtsson, Kathrine Segel, Henrietta Havsteen-Mikkelsen, and Tim Padfield, "The Physics of Drying Cloth"; http://www conservationphysics.org/wetstuff/wetstuff01.php.

Estimated Heat and Moisture Content for the Simulated Waste Wood Challenge Recipe

Simulated Waste Component(s) [See Table 3-3 and App. B]	Weight Percent (%)	Lbs Per Ton of Waste	Moisture content	Heat Content[1] (Dry Basis) (Btu/lb)	Heat Content (Btu)	Moisture Content Reference and Assumptions	Heat Content Reference and Assumptions
Corrugated Cardboard	10%	200	10.5%	8,250	1,476,750	Ref. 16; Range between 9 and 12%	Ref. 17
Paper	6%	120	4.5%	3,350	383,910	Ref. 18; Xerox® target moisture content	Ref. 17
Food waste (total)	21%	420	75%	4,588	490,056	See below	See below
Dog food	4.4%	87	8%	2,252	181,283	Internet search; Assumed 8% moisture	Internet search; Assumed 284 kcal/8 oz. cup
Vegetable oil	1.3%	26	0%	17,832	468,090	Assumed moisture content is negligible	Ref. 19; Assumed canola oil
Water	15.3%	306	100%	-	-	NA	NA
Plastic (total)	10%	200	0%	13,233	2,646,656	See below	See below
#1 PET	4.0%	80	0%	10,250	820,000	Assumed moisture content is negligible	Ref. 17
#2 HDPE	1.8%	36	0%	19,000	684,000	Assumed moisture content is negligible	Ref. 17
#3 PVC	0.6%	12	0%	8,250	99,000	Assumed moisture content is negligible	Ref. 17
#4 LDPE	1.8%	36	0%	12,050	433,800	Assumed moisture content is negligible	Ref. 17
#5 PP	0.2%	4	0%	19,000	76,000	Assumed moisture content is negligible	Ref. 17
#6 PS	1.2%	24	0%	17,800	427,200	Assumed moisture content is negligible	Ref. 17
#7 Other	0.4%	8	0%	13,332	106,656	Assumed moisture content is negligible	Ref. 20; Assumed polycarbonate
Wood	43%	860	10%	8,260	6,393,240	Ref. 21; Estimated equilibrium moisture content	Ref. 20; Assumed white pine
Metals (total)	4%	80	0%	-	-	See below	See below
Aluminum	1.4%	28.8	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Ferrous	2.4%	48	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Non-ferrous	0.2%	3.2	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Glass	1%	20	0%	-	-	Assumed moisture content is negligible	Assumed heat content is negligible
Rubber/Neoprene	1%	20	0%	14,025	280,500	Assumed moisture content is negligible	Ref. 20; Assumed car tires
Textile	2%	40	9%	7,937	288,907	Ref. 22; Estimated equilibrium moisture content	Ref. 20; Assumed cotton shirts
Misc./Other	2%	40	70%	1,025	12,262	Estimated based on simulated components	Estimated based on simulated components
Totals	**100%**	**2000**	**22.9%**		**12,131,598**		

6,066	**Btu/lb waste (wet basis)**
12.1	**MMBtu/ton waste (wet basis)**
22.9%	**Moisture Content**

[1] Quantity reported as the Higher Heating Value (HHV).

References:

16. CargoHandbook com; http://www.cargohandbook.com/index.php/Cardboard.

17. Methodology for Allocating Municipal Solid Waste to Biogenic/Non-Biogenic Energy; U.S. Energy Information Administration (EIA); Office of Coal, Nuclear, Electric, and Alternate Fuels, Washington, DC., May 2007; http://www.eia.gov/totalenergy/data/monthly/pdf/historical/msw.pdf.

18. Xerox®; http://www.xerox.com/downloads/usa/en/s/supp_lib_Helpful_Facts_About_Paper.pdf.

19. Anastasios Argeros, Dan Pincus, Zachary Shinar, and Andrea Sultenfuss, "Heat of Combustion of Oils", April 1998.

20. V. Babrauskas, “Heat of Combustion and Potential Heat,” in Heat Release in Fires, V. Babrauskas, S.J. Grayson, eds., Chapter 8, pp. 207-223, Elsevier Applied Science, London, 1992; http://fire.nist.gov/bfrlpubs/fire92/PDF/f92030.pdf.

21. William T. Simpson, Conrad Lumber Company, Wood Handbook, Chapter 12, "Drying and Control of Moisture Content and Dimensional Changes"; http://www.conradlumberco.com/pdfs/ch12_Drying_Control_of_Moisture.pdf.

22. Kaisa Bengtsson, Kathrine Segel, Henrietta Havsteen-Mikkelsen, and Tim Padfield, "The Physics of Drying Cloth"; http://www.conservationphysics.org/wetstuff/wetstuff01.php.

Appendix C. Example Air Emissions Regulation Comparison

Example Air Emissions Regulations Comparison

Species	Overseas Guidance [1,2] (Ref. 4)	NAAQS [4] (Ref. 5)	EPA OSWI (Ref. 6)	European Parliament [15] (Ref. 7)
Particulate Matter (PM)	24 mg/dscm	(See $PM_{2.5}$ and PM_{10})	0.013 gr/dscf (30 mg/dscm)	10 mg/m^3
Particulate Matter ($PM_{2.5}$)	NA	(See below)	NA	NA
Primary	NA	0.012 mg/m^3 [5]	NA	NA
Secondary	NA	0.015 mg/m^3 [5]	NA	NA
Primary and Secondary	NA	0.035 mg/m^3 [6]	NA	NA
Particulate Matter (PM_{10})	NA	0.150 mg/m^3 [7]	NA	NA
Opacity	10 percent	NA	10 percent	NA
NO_x	500 ppmv	(See NO_2)	103 ppmdv	200 mg/m^3 (~100 ppmv)
NO_2	(See NO_x)	(See below)	(See NO_x)	(See NO_x)
Primary	NA	0.100 ppm [8]	NA	NA
Primary and Secondary	NA	0.053 ppm [9]	NA	NA
SO_2	80% reduction or 30 ppmv	(See below)	3.1 ppmdv	50 mg/m^3 (~20 ppmv) [16]
Primary	NA	0.075 ppm [10]	NA	NA
Secondary	NA	0.5 ppm [11]	NA	NA
Dioxins/Furans	13 ng/dscm	NA	33 ng/dscm	0.1 ng/m^3 [17]
Cadmium	20 µg/dscm	NA	18 µg/dscm	50 $\mu g/m^3$ (includes Thallium) [18]
Lead	200 µg/dscm	0.15 $\mu g/m^3$ [12]	226 µg/dscm	500 $\mu g/m^3$ (includes Sb, As, Cr, Co, Cu, Mn, Ni, V) [18]
Mercury	85% reduction or 80 µg/dscm	NA	74 µg/dscm	50 $\mu g/m^3$ [18]
HCl	80% reduction or 30 ppmv	NA	15 ppmdv	10 mg/m^3 (~7 ppmv)
HF	NA	NA	NA	1 mg/m^3 (~1 ppmv)
Fugitive Ash	5% of hourly observation period	NA	NA	NA
CO	50 ppmv [3]	9-35 ppm [13]	40 ppmdv	50 mg/m^3 (~40 ppmv) [16]
Ozone	NA	0.075 ppm [14]	NA	NA
Total Organic Carbon (TOC)	NA	NA	NA	10 mg/m^3 (~20 ppmv)

NA - Not applicable or not defined by requirement
dscf - dry standard cubic feet
dscm - dry standard cubic meter
gr - grains
ppm - parts per million
ppmdv - parts per million dry volume
ppmv - parts per million volume
$PM_{2.5}$ - fine particles smaller than 2.5 μm in diameter
PM_{10} - inhalable course particles larger than 2.5 μm and smaller than 10 μm in diameter

[1] Emission standards and operating limit values shown are for new incinerators of 35-250 tpd capacity (lowest size available).

[2] All standards (except for CO) are stated at 7% oxygen, dry basis at standard conditions (20 °C, 1 atm).

[3] CO value is for modular starved-air type incinerator at 4-h average.

[4] “Primary” standards provide public health protection, including protecting the health of “sensitive” populations such as asthmatics, children, and elderly. “Secondary” standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

[5] Annual Averaging Time; annual mean, averaged over 3 years.

[6] 24-h Averaging Time; 98th percentile, averaged over 3 years.

[7] 24-h Averaging Time; Primary and Secondary; not to be exceeded more the once per year on average over 3 years.

[8] 1-h Averaging Time; 98th percentile, averaged over 3 years.

[9] Annual Averaging Time; Annual mean.

[10] 1-h Averaging Time; 99th percentile of 1-h daily maximum concentrations, averaged over 3 years.

[11] 3-h Averaging Time; Not to be exceeded more than once per year.

[12] Primary and secondary; Rolling 3-month average; Not to be exceeded.

[13] Primary standard only; 8-h averaging time (9 ppm); 1-h averaging time (35 ppm); not to be exceeded more than once per year.

[14] Primary and secondary; 8-hour averaging time; annual fourth-highest daily maximum 8-h concentration, averaged over 3 years.

[15] Reported as daily average values unless otherwise noted. For comparison purposes, concentrations in mg/m^3 have been converted to ppmv assuming a temperature of 25 °C. NO_x is expressed as nitrogen dioxide. TOC is expressed as carbon.

[16] 50 mg/m^3 of combustion gas determined as daily average value; 150 mg/m^3 of combustion gas of at least 95% of all measurements determined as 10-minute average values or 100 mg/m^3 of combustion gas of all measurements determined as half-hourly average values taken in any 24-h period.

[17] Average values shall be measured over a sample period of a minimum of 6 h and a maximum of 8 h. Calculated using the concept of toxic equivalence.

[18] All average values over the sample period of a minimum of 30 min and a maximum of 8 h.

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Appendix D. Air Emissions Characterization Example Method Descriptions and Test Standard Target Compounds

Air Emissions Characterization
Example Method Descriptions

			NSRDEC/ARL Test Standard			
Analysis[1]	**Methods[2]**	**Ref.**	**Req'd.**	**Other Recom'd**	**EPA OSWI[3]**	**Method Descriptions[4]**
Carbon Monoxide (CO)	EPA Method 10 (Ref. 12) 10A (Ref. 10) 10B	10,12	✓		✓	EPA Method 10 - Determination of Carbon Monoxide Emissions From Stationary Sources (Instrumental Analyzer Procedure). http://www.epa.gov/ttnemc01/promgate/method10r06.pdf EPA Method 10A - Determination of Carbon Monoxide Emissions in Certifying Continuous Emissions Monitoring Systems (CEMS) at Petroleum Refineries. http://www.epa.gov/ttnemc01/promgate/m-10a.pdf EPA Method 10B - Determination of Carbon Monoxide Emissions From Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-10b.pdf
Carbon Dioxide (CO_2)	EPA Method 3A	9,10,11, 12	✓			EPA Method 3A - Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure). http://www.epa.gov/ttn/emc/promgate/method3A.pdf
Oxygen (O_2)	EPA Method 3A	9,10,12	✓			EPA Method 3A - Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure). http://www.epa.gov/ttn/emc/promgate/method3A.pdf

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard		EPA OSWI[3]	Method Descriptions[4]
			Req'd.	Other Recom'd		
Nitrogen Oxides (NO_x)	EPA Method 7	9,10,12	✓		✓	EPA Method 7 – Determination of Nitrogen Oxide Emissions from Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-07.pdf
	EPA Method 7A					EPA Method 7A – Determination of Nitrogen Oxide Emissions from Stationary Sources (Ion Chromatographic Method). http://www.epa.gov/ttnemc01/promgate/m-07a.pdf
	EPA Method 7C					EPA Method 7C – Determination of Nitrogen Oxide Emissions from Stationary Sources (Alkaline Permanganate/Colorimetric Method). http://www.epa.gov/ttnemc01/promgate/m-07c.pdf
	EPA Method 7D					EPA Method 7D – Determination of Nitrogen Oxide Emissions from Stationary Sources (Alkaline Permanganate/Ion Chromatographic Method). http://www.epa.gov/ttnemc01/promgate/m-07d.pdf
	EPA Method 7E					EPA Method 7E - Determination of Nitrogen Oxides Emissions From Stationary Sources (Instrumental Analyzer Procedure). http://www.epa.gov/ttn/emc/promgate/method7E.pdf
Sulfur Dioxide (SO_2)	EPA Method 6	10,12	✓		✓	EPA Method 6 - Determination of Sulfur Dioxide Emissions from Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-06.pdf
	EPA Method 6C (Ref. 10,12)					EPA Method 6C - Determination of Sulfur Dioxide Emissions from Stationary Sources (Instrumental Analyzer Procedure). http://www.epa.gov/ttn/emc/promgate/method6C.pdf
Total Organic Compounds (TOCs)	EPA Method 25A	12	✓			EPA Method 25A - Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer. http://www.epa.gov/ttnemc01/promgate/m-25a.pdf

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard Req'd.	NSRDEC/ARL Test Standard Other Recom'd	EPA OSWI[3]	Method Descriptions[4]
Volatile Organic Compounds (VOCs)	EPA Method SW-846 0030 (Ref. 12) and SW-846 8260C or EPA Compendium Method TO-15 (Ref. 10,11)	10,11, 12		✓		EPA SW-846 Method 0030 - Volatile Organic Sampling Train. http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/0030.pdf EPA SW-846 Method 8260C – Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS). http://www.epa.gov/solidwaste/hazard/testmethods/pdfs/8260c.pdf EPA Compendium Method TO-15 - Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). Cincinnati, OH, 1999, EPA/625/R-96/010b. http://www.epa.gov/ttn/amtic/files/ambient/airtox/to-15r.pdf Note: Modifications would need to be made to TO-15 for use with stack sampling.
Semi-Volatile Organic Compounds (SVOCs)	EPA Method SW-846 0010 (Ref. 12) and SW-846 8270	12		✓		EPA SW-846 Method 0010 - Modified Method 5 Sampling Train. Analysis method not specified in reference 9. http://www.epa.gov/solidwaste/hazard/testmethods/sw846/pdfs/0010.pdf EPA SW-846 Method 8270 - Semivolatile Organic Compounds (SVOC) by Gas Chromatography/Mass Spectrometry (GC/MS). http://www.epa.gov/region9/qa/pdfs/8270.pdf

			NSRDEC/ARL Test Standard			
Analysis[1]	**Methods[2]**	**Ref.**	**Req'd.**	**Other Recom'd**	**EPA OSWI[3]**	**Method Descriptions[4]**
Polycyclic Aromatic Hydrocarbons (PAHs)	EPA Method SW-846 0010 (Ref. 10,12) and SW-846 8270 (Ref. 10) TO-13A (Ref. 11)	10,11, 12	✓			EPA SW-846 Method 0010 - Modified Method 5 Sampling Train. http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/0010.pdf EPA SW-846 Method 8270 - Semivolatile Organic Compounds (SVOC) by Gas Chromatography/Mass Spectrometry (GC/MS). http://www.epa.gov/region9/qa/pdfs/8270.pdf EPA Compendium Method TO-13A - Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Ambient Air Using Gas Chromatography/Mass Spectrometry (GC/MS). http://www.epa.gov/ttnamti1/files/ambient/airtox/to-13arr.pdf Note: Modifications would need to be made to TO-13A for use with stack sampling.
Hydrogen Halides and Halogens	EPA Method 26A	9,12	✓ HCl	✓ Br_2 Cl_2 HBr HF	✓ HCl	EPA Method 26A - Determination of Hydrogen Halide and Halogen Emissions From Stationary Sources Isokinetic Method. http://www.epa.gov/ttnemc01/promgate/m-26a.pdf For reference 9, only HCl was analyzed and it was noted that the EPA Method 26A sample train for HCl determination was run as part of the EPA Method 5 sample train. Note: Test Standard required and EPA OSWI guidelines are for HCl only.

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard Req'd.	NSRDEC/ARL Test Standard Other Recom'd	EPA OSWI[3]	Method Descriptions[4]
Polychlorinated Dioxins/Furans	EPA Method 23 (Ref. 12) EPA Method TO-9A (Ref. 10,11)	10,11, 12	✓		✓	EPA Method 23 - Determination of Polychlorinated Dibenzo-p-Dioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) from Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-23.pdf EPA Compendium Method TO-9A - Determination of Polychlorinated, Polybrominated and Brominated/Chlorinated Dibenzo-p-Dioxins and Dibenzofurans in Ambient Air. http://www.epa.gov/ttn/amtic/files/ambient/airtox/to-9arr.pdf Note: Modifications would need to be made to TO-9A for use with stack sampling.
Polybrominated Dioxins/Furans	EPA Method TO-9A	10,11		✓		EPA Compendium Method TO-9A - Determination of Polychlorinated, Polybrominated and Brominated/Chlorinated Dibenzo-p-Dioxins and Dibenzofurans in Ambient Air. http://www.epa.gov/ttn/amtic/files/ambient/airtox/to-9arr.pdf Note: Modifications would need to be made to TO-9A for use with stack sampling.
Metals	EPA Method 29 (Ref. 12) EPA Method IO-3.4 (Ref. 10,11)	10,11, 12	✓		✓	EPA Method 29 - Determination of Metals Emissions from Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-29.pdf EPA Compendium Method IO 3.4. Determination of Metals in Ambient Particulate Matter Using Inductively Coupled Plasma (ICP) Spectroscopy, EPA/625/R-96/-0101a. http://www.epa.gov/ttn/amtic/files/ambient/inorganic/mthd-3-4.pdf

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard Req'd.	NSRDEC/ARL Test Standard Other Recom'd	EPA OSWI[3]	Method Descriptions[4]
Particulate Matter (PM)	EPA Methods 1A through 5 (Ref. 9) or EPA Method 29	9	✓		✓	EPA Method 5 – Determination of Particulate Emissions from Stationary Sources. http://www.epa.gov/ttn/emc/promgate/m-05.pdf EPA Method 29 - Determination of Metals Emissions from Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-29.pdf Note: This method may be used to determine particulate emissions in addition to the metals emissions if the prescribed procedures and precautions are followed.
Particulate Matter (PM) for $PM_{2.5}$ and PM_{10}	EPA Method 5, 201A, 202	10,11, 12	✓			EPA Method 5 – Determination of Particulate Emissions from Stationary Sources. http://www.epa.gov/ttn/emc/promgate/m-05.pdf EPA Method 201A - Determination of PM_{10} and $PM_{2.5}$ Emissions from Stationary Sources (Constant Sampling Rate Procedure). http://www.epa.gov/ttn/emc/promgate/m-201a.pdf EPA Method 202 - Dry Impinger Method For Determining Condensable Particulate Emissions From Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-202.pdf Note: Ref. 10, 11, and 12 performed analyses for $PM_{2.5}$ with various analytical methodologies (EPA Methods 5, IO-3.4, 202, and 40 CFR Part 50, Appendix J). Ref. 10 also performed analyses for PM_{10} using EPA Method 5.
Visible Emissions/ Opacity	EPA Method 9	12	✓		✓	EPA Method 9 - Visual Determination of the Opacity of Emissions from Stationary Sources. http://www.epa.gov/ttnemc01/promgate/m-09.pdf
Moisture Content	EPA Method 4	N/A	✓			Method 4 - Determination Of Moisture Content In Stack Gases. http://www.epa.gov/ttnemc01/promgate/m-04.pdf Note: Moisture content is required to report other analytes on a dry basis.

[1] Additional analyses may be required depending on permitting requirements, system characterization needs, and process monitoring requirements.

[2] Methods were obtained from the reference documents as shown or included due to their common use in industry. All methods shown should be considered as examples only. Specific sampling and analysis procedures should be selected appropriately for each test program and documented in a sampling and analysis plan.

[3] EPA Other Solid Waste Incinerators (OSWI) Guidelines (Ref. 6).

[4] Method descriptions may include more recent versions of the sampling or analytical methods provided in the reference documents.

Analysis	Target Compounds	Ref.	Notes
PAHs	3-Methylcholanthrene 7,12-Dimethylbenz(a)-anthracene Acenaphthene Acenaphthylene Anthracene Benzo(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene Benzo(k)fluoranthene Chrysene Dibenz(a,j)acridine Dibenzo(a,e)pyrene Dibenzo(a,h)anthracene Fluoranthene Fluorene Indeno(1,2,3-cd)pyrene Naphthalene Phenanthrene Pyrene	10,11,12	This is the complete list of the PAHs from EPA Method 8270. Note: Ref. 11 used TO-13A for ambient air that has a slightly different list of target compounds.
Hydrogen Halides and Halogens	Bromine (Br_2) Chlorine (Cl_2) Hydrogen Bromide (HBr) Hydrogen Chloride (HCl) Hydrogen Fluoride (HF)	9,12	This is the complete list from EPA Method 26A. Note: Test Standard required and EPA OSWI guidelines are for HCl only.
Polychlorinated Dioxins/Furans	2,3,7,8-TCDD Total TCDD 2,3,7,8-TCDF Total-TCDF 1,2,3,7,8-PeCDD Total-PeCDD 1,2,3,7,8-PeCDF 2,3,4,7,8-PeCDF Total-PeCDF 1,2,3,4,7,8-HxCDD 1,2,3,6,7,8-HxCDD 1,2,3,7,8,9-HxCDD Total-HxCDD 1,2,3,4,7,8-HxCDF 1,2,3,6,7,8-HxCDF 1,2,3,7,8,9-HxCDF 2,3,4,6,7,8-HxCDF Total-HxCDF 1,2,3,4,6,7,8-HpCDD Total-HpCDD 1,2,3,4,6,7,8-HpCDF 1,2,3,4,7,8,9-HpCDF Total-HpCDF 1,2,3,4,6,7,8,9-OCDD 1,2,3,4,6,7,8,9-OCDF	10,11,12	This is the complete list from EPA Method 23 with additional compounds listed in EPA Method 1613. Chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans: TCDD = Tetrachlorodibenzo-p-dioxin TCDF = Tetrachlorodibenzofuran PeCDD = Pentachlorodibenzo-p-dioxin PeCDF = Pentachlorodibenzofuran HxCDD = Hexachlorodibenzo-p-dioxin HxCDF = Hexachlorodibenzofuran HpCDD = Heptachlorodibenzo-p-dioxin HpCDF = Heptachlorodibenzofuran OCDD = Octachlorodibenzo-p-dioxin OCDF = Octachlorodibenzofuran

Analysis	Target Compounds	Ref.	Notes
Metals	Antimony (Sb)		Test Standard includes all 18 metals from EPA Method 29 as shown.
	Arsenic (As)	10,11,12	
	Barium (Ba)		
	Beryllium (Be)		Note: EPA OSWI guidelines (Ref. 6) require only Cd, Pb, and Hg.
	Cadmium (Cd)	10,11,12	
	Chromium (Cr)	10,11,12	
	Cobalt (Co)		
	Copper (Cu)	10,11	
	Iron (Fe)	10,11	
	Lead (Pb)	10,11,12	
	Manganese (Mn)	12	
	Mercury (Hg)	10,11,12	
	Nickel (Ni)	10,11,12	
	Phosphorus (P)		
	Selenium (Se)		
	Silver (Ag)		
	Thallium (Tl)		
	Zinc (Zn)		

Appendix E. Solid Residue and Liquid Effluent Characterization Example Method Descriptions and Test Standard Target Compounds

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard Req'd.	NSRDEC/ARL Test Standard Other Recom'd.	EPA Guidance[3]	Method Descriptions[4]
TCLP Volatile Organic Compounds (VOCs)	EPA SW-846 Method 1311 and 8260	12,13	✓	✓ Additional target compounds can be selected from EPA Method 8260	✓	EPA SW-846 Method 1311 - Toxicity Characteristic Leaching Procedure (TCLP). http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1311.pdf EPA SW-846 Method 8260 - Volatile Organic Compounds (VOCs). http://www.epa.gov/region9/qa/pdfs/8260.pdf Note: Ref. 12 performed analysis for solids only. Ref. 13 did not specify using the TCLP method.
TCLP Semivolatile Organic Compounds (SVOCs)	EPA SW-846 Method 1311 and 8270	12,13	✓	✓ Additional target compounds can be selected from EPA Method 8270	✓	EPA SW-846 Method 1311 - Toxicity Characteristic Leaching Procedure (TCLP). http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1311.pdf EPA SW-846 Method 8270 - Semivolatile Organic Compounds (SVOCs). http://www.epa.gov/region9/qa/pdfs/8270.pdf Note: Ref. 12 performed analysis for solids only. Ref. 13 did not specify using the TCLP method.
Polychlorinated Dioxins/Furans	EPA Method 1613	13	✓			EPA Method 1613, Revision B - Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution high resolution capillary column gas chromatography (HRGC)/high resolution mass spectrometry (HRMS). http://water.epa.gov/scitech/methods/cwa/organics/dioxins/upload/2007_07_10_methods_method_dioxins_1613.pdf

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard Req'd.	NSRDEC/ARL Test Standard Other Recom'd.	EPA Guidance[3]	Method Descriptions[4]
Polybrominated Dioxins/Furans	Modified EPA Methods (1613 and TO-9A)	13		✓		EPA Method 1613, Revision B - Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution high resolution capillary column gas chromatography (HRGC)/high resolution mass spectrometry (HRMS). http://water.epa.gov/scitech/methods/cwa/organics/dioxins/upload/2007_07_10_methods_method_dioxins_1613.pdf EPA Compendium Method TO-9A - Determination of Polychlorinated, Polybrominated and Brominated/Chlorinated Dibenzo-p-Dioxins and Dibenzofurans in Ambient Air. http://www.epa.gov/ttn/amtic/files/ambient/airtox/to-9arr.pdf Note: Modifications would need to be made to these methods for the extraction and analysis of polybrominated dioxins/furans.
Total Organic Carbon (TOC)	EPA SW-846 Method 9060	12	✓			EPA SW-846 Method 9060 – Total Organic Carbon. http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/9060a.pdf Note: Ref. 12 performed analysis for solids only.
TCLP Metals	EPA SW-846 Method 1311, 6010, and 7470	12,13	✓	✓ Additional target metals can be selected from EPA Method 6010 and 7470/7471 (Mercury only).	✓	EPA SW-846 Method 1311 - Toxicity Characteristic Leaching Procedure (TCLP). http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1311.pdf EPA Method 6010C - Inductively Coupled Plasma-Atomic Emission Spectrometry. http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/6010c.pdf SW 846 Method 7470, Revision A, Mercury in Liquid Waste (Manual Cold-Vapor Technique). http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/7470a.pdf Note: Ref. 12 performed analysis for solids only. Ref. 13 included total metals in addition to TCLP metals.

Analysis[1]	Methods[2]	Ref.	NSRDEC/ARL Test Standard Req'd.	NSRDEC/ARL Test Standard Other Recom'd.	EPA Guidance[3]	Method Descriptions[4]
Corrosivity (pH)	EPA SW-846 Method 9045	12	✓		✓	EPA SW-846 Method 9045 - pH in Liquid and Soil. http://www.epa.gov/region9/qa/pdfs/9045_1crf.pdf Note: Ref. 12 performed analysis for solids only.
Ignitability	EPA SW-846 Method 1010	12	✓		✓	EPA SW-846 Method 1010 – Test Methods for Flash Point by Pensky-Martens Closed-Cup Tester. http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/1010a.pdf Note: Ref. 12 performed analysis for solids only.
Reactivity	40 CFR §261.23		✓		✓	No analytical method. Qualitative assessment based on 40 CFR §261.23 criteria.

1 Additional analyses may be required depending on permitting requirements, system characterization needs, and process monitoring requirements.

2 Methods were obtained from the reference documents as shown or included due to their common use in industry. All methods shown should be considered as examples only. Specific sampling and analysis procedures should be selected appropriately for each test program and documented in a sampling and analysis plan.

3 EPA Guidance for the Sampling and Analysis of Municipal Waste Combustion Ash for the Toxicity Characteristic (Ref. 14); EPA Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Wastes; A Guidance Manual (Ref. 15); and 40 CFR Part 261, Subpart C, *Characteristics of Hazardous Waste*.

4 Method descriptions may include more recent versions of the sampling or analytical methods provided in the reference documents.

Analysis	Target Compound(s)	Ref.	Notes
TCLP VOCs	Benzene Carbon Tetrachloride Chlorobenzene Chloroform 1,2-Dichloroethane 1,1-Dichloroethylene Methyl Ethyl Ketone Tetrachloroethylene Trichloroethylene Vinyl Chloride	12,13	Test standard required target compounds from SW-846 chapter 7, Table 7-1, and 40 CFR Part 261, Subpart C, Characteristics of Hazardous Waste. Additional target compounds can be selected from EPA Method 8260.
TCLP SVOCs	2-Methylphenol (o-Cresol) 3-Methylphenol (m-Cresol) 4-Methylphenol (p-Cresol) 1,4-Dichlorobenzene 2,4-Dinitrotoluene Hexachlorobenzene Hexachlorobutadiene Hexachloroethane Nitrobenzene Pentachlorophenol Pyridine 2,4,5-Trichlorophenol 2,4,6-Trichlorophenol	12,13	Test standard required target compounds from SW-846 chapter 7, Table 7-1, and 40 CFR Part 261, Subpart C, Characteristics of Hazardous Waste. Additional target compounds can be selected from EPA Method 8270.
Polychlorinated Dioxins/Furans	2,3,7,8-TCDD Total TCDD 2,3,7,8-TCDF Total-TCDF 1,2,3,7,8-PeCDD Total-PeCDD 1,2,3,7,8-PeCDF 2,3,4,7,8-PeCDF Total-PeCDF 1,2,3,4,7,8-HxCDD 1,2,3,6,7,8-HxCDD 1,2,3,7,8,9-HxCDD Total-HxCDD 1,2,3,4,7,8-HxCDF 1,2,3,6,7,8-HxCDF 1,2,3,7,8,9-HxCDF 2,3,4,6,7,8-HxCDF Total-HxCDF 1,2,3,4,6,7,8-HpCDD Total-HpCDD 1,2,3,4,6,7,8-HpCDF 1,2,3,4,7,8,9-HpCDF Total-HpCDF 1,2,3,4,6,7,8,9-OCDD 1,2,3,4,6,7,8,9-OCDF	13	Complete suite listed in EPA Method 1613. Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans: TCDD = Tetrachlorodibenzo-p-dioxin TCDF = Tetrachlorodibenzofuran PeCDD = Pentachlorodibenzo-p-dioxin PeCDF = Pentachlorodibenzofuran HxCDD = Hexachlorodibenzo-p-dioxin HxCDF = Hexachlorodibenzofuran HpCDD = Heptachlorodibenzo-p-dioxin HpCDF = Heptachlorodibenzofuran OCDD = Octachlorodibenzo-p-dioxin OCDF = Octachlorodibenzofuran

Analysis	Target Compound(s)	Ref.	Notes
TCLP Metals	Arsenic (As)	12,13	Test standard required target compounds from SW-846 chapter 7, Table 7-1, and 40 CFR Part 261, Subpart C, Characteristics of Hazardous Waste.
	Barium (Ba)	12,13	
	Cadmium (Cd)	12,13	
	Chromium (Cr)	12,13	
	Lead (Pb)	12,13	
	Mercury (Hg)	12,13	Additional target metals can be selected from EPA Method 6010 and 7470/7471 (Mercury only).
	Selenium (Se)	12,13	
	Silver (Ag)	12,13	

List of Symbols, Abbreviations, and Acronyms

ABS	poly(acrylonitrile butadiene styrene)
ARL	US Army Research Laboratory
ATM	standard sea level pressure (atmosphere)
BCIL	Base Camp Integration Laboratory
BTU	British thermal unit
CERL	Construction Engineering Research Laboratory
CFR	Code of Federal Regulations
CO	carbon monoxide
CO_2	carbon dioxide
COI	community of interest
CPD	Capability Production Document
DOD	Department of Defense
dscf	dry standard cubic feet
dscm	dry standard cubic meter
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
FPE	force provider expeditionary
gr	grains
HCl	hydrochloric acid
HDPE	high density polyethylene
JDW2E	Joint Deployable Waste to Energy
LDPE	low density polyethylene
MAGS	micro auto gasification system
MMBTU	one million BTUs
MRE	meal, read-to-eat

MSW	municipal solid waste
NAAQS	National Ambient Air Quality Standards
NDCEE	National Defense Center for Energy and Environment
NO_x	nitrogen oxides
NSRDEC	Natick Soldier Research, Development and Engineering Center
O_2	oxygen
OSWI	other solid waste incineration
PAHs	polycyclic aromatic hydrocarbons
PAX	personnel
PET	polyethylene terephthalate
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
PM	particulate matter
$PM_{2.5}$	particulate matter smaller than 2.5 microns
PM_{10}	particulate matter between 2.5 and 10 microns
PM-FSS	Product Manager Force Sustainment Systems
PP	polypropylene
ppm	parts per million
ppmdv	parts per million dry volume
ppmv	parts per million volume
PS	polystyrene
PVC	polyvinyl chloride
SO_2	sulfur dioxide
SPF	spruce, pine, or fur
SVOCs	semi-volatile organic compounds
TCLP	toxicity characteristic leaching procedure

TOC	total organic carbon
TOCs	total organic compounds
tpd	tons per day
UGR-A	Unitized Group Ration - A Option
USACE	US Army Corps of Engineers
USAPHC	US Army Public Health Command
USC	United States Code
VOCs	volatile organic compounds
WTE	waste-to-energy

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